ARCHITECTURAL ACOUSTICS

OR

The Science of Sound Application Required in the Construction of Audience Rooms.

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BUFFALO, N. Y.

PRICE, TEN DOLLARS.

BENSLER & WESLEY PRINT,
BUFFALO, N. Y.

SYNOPSIS OF PRINCIPLES INVOLVED.

THE following is a synopsis of this volume, which embodies the principles required for the design and construction of all buildings containing auditoriums that are intended to be used for the purpose of public entertainments of oratory or music; treating on the propagation of sound; its manipulation and control by such methods as are required to afford perfect hearing.

1st. Propagation of sound is the physical or mechanical method of causing air to assume vibrations, consisting of regular and irregular air waves.

2d. Hearing is the action of the air on the tympanum of the ear; its conductive power to the inner ear, and its final transmission to the brain through the enshrouded mystery of the Infinite.

3d. The divided result of hearing is noise, sound and tone; their difference being due to the form, composition and volume of the air waves in vibration.

4th. Noise is an explosion or concussion of air, having irregular and uneven air waves in form, volume and composition.

5th. Sound is a graduated vibration of air waves in volume, number and composition, and possessed of the qualities of Dead, Harsh, Cold, Rich, Warm, Pure and Live Sounds. *See page 33.*

6th. Tone is a periodical vibration of air waves, having for its component parts—Duration, Pitch, Volume, Timbre, Life, Luster, Dynamics and Movements.

7th. Duration is the property of existence measured by time, the method being demonstrated in music by characters employed to measure, divide and proportion the quantity or length of duration.

8th. Pitch is the graduated scale by which the number of air vibrations are determined and registered by the ear to a second of a time; or, a specific quantity of duration.

9th. Volume is the size and density of the air vibrations; the cubical quantity of air in action or disturbance.

10th. Timbre is the quality, form and amplitude of air vibrations.

11th. Life is the design of the issue, the mould of duration and the dismissal of sound.

12th. Lustre is the proper enunciation or articulation of language; the correct intonation and moulding of vowels; the clean cut, crisp issue and dismissal of consonants.

13th. Dynamics are the laws that control and guide the successive motions or movements developed by time.

14th. Movement is a series of actions and positions that the human figure assumes to demonstrate the requirements of time.

15th. Sound waves travel in straight lines from point of propagation to silence by vibratory exhaustion, unless deflected out of their paths by obstructions.

16th. Sound waves always rebound from hard or smooth surfaces, *i. e.*, the angle of incidence is always equal to the angle of reflection. *See page 65 and 80.*

17th. Sound waves reflected from a circular wall condense or focus at or near the generating point of the circle used. *See page 35.*

18th. Sound waves reflected from a curved wall or surface have a tendency to parallel or radiate from the reflector according to the location of the sound propagation or point of issue. *See page 83.*

19th. Sound waves are absorbed, nullified or die out on dead or non-reflecting walls of soft absorbent material, such as carpets, wall draperies, plush or velvet, portieres, etc., etc. *See page 66.*

20th. A sound reflection is a volume of vibration which, brought into contact with a surface, rebounds from the surface on an angle that is always equal to the angle of its contact.

21st. A node is a location of silence on a bisecting angle between the angle of contact and the angle of reflection, and is always at right angles with the surface at the point of sound contact.

22d. An echo is a returning sound wave, having an intervening silence between it and the next outgoing primary sound wave. *See page 36.*

23d. A crash is a blind echo and a primary wave in collision without an intervening silence; also a lapping collision between two returning waves at the junction angle of a room. *See page 35.*

24th. A jar is a returning sound wave focusing and lapping on a primary sound wave; also a returning sound wave condensing at the focal generating point underneath domes. *See page 35.*

25th. A flutter is a primary sound wave in contact with a circular wall or ceiling when the point of sound issue is at the side of, or on a tangent to, the reflecting surface. *See page 36.*

26th. A reverberation is a sound wave forced to a point beyond vibratory cohesion, or to such an extent that the fundamental wave is separated from its upper harmonic waves, heard in detached chunks of sound in the upper rear corners of the room. *See page 34.*

27th. Resonance is the flexibility of sound waves, or the property enclosed air pockets possess of continuing vibration after propagation of sound ceases.

28th. Oratory is the cultivated delivery of language in accordance with established rules of elocution.

29th. Music is a combination of tones set to characters which represent melody, harmony and dissonance.

30th. Melody is an agreeable succession of rythmical single tones, individual, in order of propagation, and creating a musical theme.

31st. Harmony is the simultaneous propagation of two or more tones, the number of their vibrations having a common divisor; a combination of tones that are agreeable to the ear.

32d. A dissonance or discord is the simultaneous propagation of two or more tones, the number of their air vibrations not having a common divisor. For example: Odd and even numbers in unison, as the pitches of C and D on the piano uttered simultaneously.

force. Sound reacts and reflects from surfaces on an angle equal to the angle of contact; *i. e.*, "The angle of incidence is equal to the angle of reflection." Sound reacts, condenses and re-enforces itself at or near the focus of circles. Sound reacts in parallel lines from curves when they are constructed on the primary nodal lines which produce hyperbolic and evoluting curved surfaces. Sound dies on soft or dead surfaces, as carpet, drapery, etc., velvet being the best known material for exhausting sound waves, while a polished plate glass or metal mirror is the best reflector of sound waves. A Node is a bisecting location indicated by a line or point midway between the angle of incidence and the angle of reflection. A Node is always at right angles with the surface at the point of contact. An ECHO is a returning sound wave with an intervening silence between the primary and returning wave. A Crash is a primary wave and an echo in collision, without intervening silence; a lapping of the returning wave on the primary wave. A JAR is a returning wave focusing at or near the center of a concave surface. Dead sounds are waves that are cut off from the center of propagation by the interference of echos, crashes, jars, heat currents, draperies, etc. Speaking sounds are dead air enclosed in pockets that assume vibratory motion when their corresponding pitch is struck on a musical instrument.

RESONANCE is the flexibility of sound waves, or the property that air possesses of continuing in vibration after propagation ceases, or the effect of a vibration of air returning from a surface or concavity and re-enforcing the primary vibratory motion of the air. Resonance is Sympathetic, Simple, Primary, Nodal, Compound and Complex.

HOMOGENEITY is the uniform degree of the density of the air. For perfect sound propagation the air must be of an even strata, free from all currents, draughts, etc. This principle controls all heating and lighting apparatus.

REFLECTION is the property that sound waves possess of continuing to travel after striking any obstruction having a hard surface. The shape and material composition of the obstruction governs the sound wave and produces Echos, Crashes, Jars, Resonance, etc.

By recapitulation of the above-outlined principles we find that, for acoustically correct audience rooms, they must be constructed—

First—So that the propagation of sound will be perfect in Intonation, Pitch, Voicing and Timbre.

Second—That the walls and ceilings be so constructed in their form that all returning sound waves will travel in parallel lines, or return on their primary paths; that all conflicting or focusing walls or ceilings be constructed as dead or non-reflecting surfaces.

Third—That the heating, ventilating and lighting apparatus be so located as to cause the entire air of the audience room to be composed of an even homogeneity, devoid of all draughts or air currents.

Fourth—That all dead or dull speaking sound locations be re-enforced by simple resonance pockets or sound reflectors, giving the entire auditorium evenly-balanced volume and quality of sound.

WORDS OF CAUTION.

As a child fears and avoids fire, so it would also be wisdom on the part of those who build to avoid in every sense each and every one of the following faults wherein applied to Constructive Acoustics.

DON'T Plaster solid on to terra-cotta, brick or stone walls.

DON'T Build spherical or conical domes in the ceilings.

DON'T build circular angles or corners in the room.

DON'T Supply hot air in large quantities in center of room.

DON'T Locate lighting in center of room; distribute it.

DON'T Construct large ventilating shaft in center of room.

DON'T Supply heat in bulk through the ceiling.

DON'T Supply cold air through the floor—it is a failure.

DON'T Stretch wires across ceiling to kill echos.

DON'T Varnish the wainscoating or wax a hard-wood floor.

CHAPTER II.

OUTLINE OF FLOOR PLAN OF AUDITORIUMS.

A PERFECT egg oval is the only form of which the interior walls of an audience room can be constructed that will result in a room absolutely perfect for hearing.

The longitudinal axis of the oval should be on a level.

The seating should occupy the lower half of the room, and the curved ceiling the top half. The stage or rostrum should be at the smaller end of the oval at its focal axis.

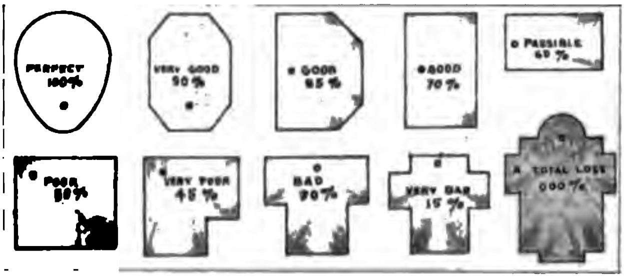
Next in order of perfection to the ovaloid shape is a rectangular-shaped room, the dimensions being in the proportion of one foot in height between the floor and ceiling to one foot from rostrum to rear walls, to each two feet in width of room across the front of the stage; *i. e.*, 50 feet from front to rear, 50 feet between floor and ceiling by 100 feet wide.

The rostrum or stage may be placed at the end of a long, narrow room with very good results if the side walls are of non-reflecting materials; but it is not the best method to use.

Strive to locate all walls and ceilings the same distance from the speaker's station.

Irregular-shaped rooms, especially those that have groined or arched ceilings, can never be made to possess good hearing qualities; at best, they can only be made useable. They will, in most cases, be total failures. Avoid them if possible.

The following forms give extreme outline shape of floor plans from perfect to total failure in hearing, beginning with 100 per cent. as perfect and 1 per cent. as failure. "O" indicates speaker's station. The clouded portions indicate sound disturbances.



CHAPTER III.

ATMOSPHERIC AIR—ITS PROPERTIES, &C.

ATMOSPHERIC AIR, the matter that surrounds the earth and extends to an unknown height, but from calculations is supposed to extend about fifty miles from the surface. Air at the sea level, under the ordinary conditions, is composed of about twenty-two parts of nitrogen and seventy-seven parts of oxygen, and one part of carbonic acid gas. Density of air is reckoned at the sea level. It is the result of the weight of a column of air one inch square, the height of about fifty miles, or the extent the atmosphere rises above the surface of the earth at sea level; the weight is approximately fifteen pounds for each square inch of column. Density rapidly decreases as we ascend, being only one-half the density at four miles in height.

Expansion and compression is the property that air possesses of changing its density, size, and also its location, from the effects of heat or cold, as a natural source, and also by mechanical apparatus. For example, take a square, clean, empty one-gallon tin can out into the cold air in winter; then tightly cork; set the can on a hot stove to heat the enclosed air; first, the sides of the can will bulge out by the expansion of the air with a crackling sound, and if heated to a high temperature the cork will blow out, or the can will explode with a loud report. Heat also changes the location of air by changing its density. Heat rarifies air, and as by the law of equilibrium, heat will seek air of a correct altitude to correspond in density with the heated air. A good example is the hot-air register; the heated air, as it escapes from the register, immediately ascends to the ceiling. The effect of air in changing locations is termed Currents, Stratas, Draughts, Breezes, Winds and Hurricanes. The heated air rises, and only cold air rushes in to fill the vacancy or partial vacuum thus formed.

Flexibility is the property that air possesses of assuming its former density and location when disturbed by mechanical (not heat) appliances. It will immediately assume repose the instant mechanical disturbances cease.

Nodes are silence or the rarified air between air waves or vibrations. Nodal lines are at right angles with reflecting walls, and are always midway between the angle of Incidence and the angle of Reflection.

VIBRATION. The result of density, expansion and contraction controlled by flexibility is termed Vibration, when used mechanically, and known as Noise, Sound or Tone, according to the kind of vibratory motion employed, of which there are three kinds—Regular, Irregular, and Specific.

The effect of a vibration of air returning from a surface or cavity and re-enforcing the primary vibratory motion of the air, is termed resonance—there being Sympathetic, Simple, Primary, Nodal, Compound and Complex. Simple resonance is a direct re-enforcement of a simple vibration. A primary resonance is the lapping of two uniform waves so that their condensation and rarefaction will correspond or coincide. Nodal resonance is a resonance between the vibrations. Compound resonance is two or more returning resonances from different sources at the same time. Complex resonance is two or more resonances from different sources crossing paths and re-enforcing primary vibrations at different intervals.

All sounding pockets the dimensions of which are less than the length of the sound waves which they produce in giving forth resonance are properly termed primary or simple resonance pockets. Any enclosed space of any form known are sounding pockets, as all enclosed air will respond when sympathetic pitch is struck on any musical instrument in close proximity to an opening if from the outside, and near the center if from the inside. Some curious facts exist to bear out the above statement.

DEMONSTRATED SIMPLE RESONANCE.

Take a one quart bottle and sound a whistle on as low a pitch as possible, and gradually raise the pitch until the sympathetic

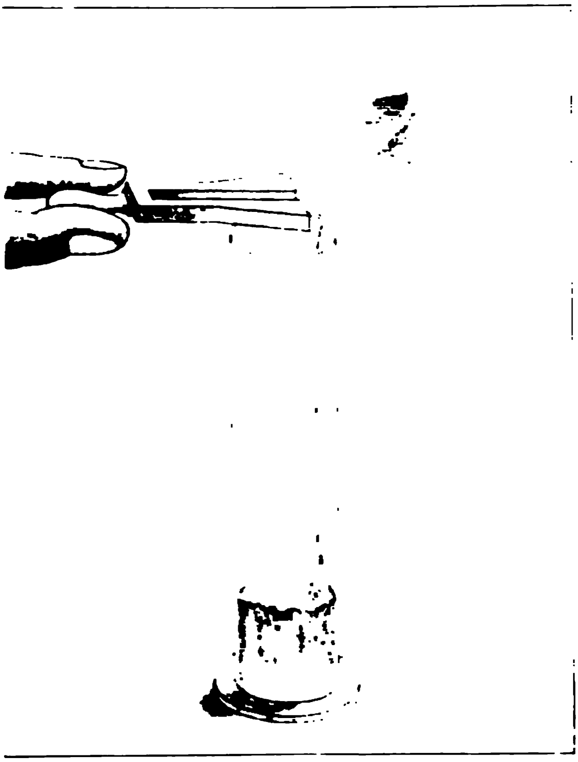
tone is struck, when the bottle will immediately assume sympathetic vibrations by an audible sound apparently issuing from the bottle which will re-enforce the whistle both in strength and quality.

Some honey was left, after emptying, in the bottom of a wide-mouthed bottle, when the following interesting sight occurred: Attracted by the scent of the honey, various kinds of flies and bees lit on the edge of the mouth of the bottle and walked down the inside of the bottle to steal a sweet morsel for their noon-day lunch. The bottle was lightly tapped with a pencil, frightening the insects, who immediately took flight. As they passed out of and at a level with the top of the mouth of the bottle, the bottle would give forth a sound loud enough to be heard thirty feet or more.

A thread being smeared with honey and drawn across the mouth of the bottle, with a common house fly of large size stuck to the honey over the center of the opening, the vibrations of the fly's wings in its struggle to escape caused the bottle to resound loud enough to be heard seventy-two feet.

Take a tube any size or length and hold a tuning fork over the top while in vibration. Gradually fill the tube with water by a funnel and when the water has reached the proper height for

resonance, the air above the water will respond to the vibrations of the fork, which it will re-enforce and cause to produce an audible sound.



If the fork be slowly revolved between the thumb and finger while in vibration it will emit a low, velvety, musical tone that is composed of a series of undulating, periodical, sinuous swells or pulsations, which produce nearly the same sensation on the ear that the human pulse does to the nerves of the thumb if applied to the artery on inside of the wrist. The tube will also produce a perfect graduation of pitch as the water rises in the tube.

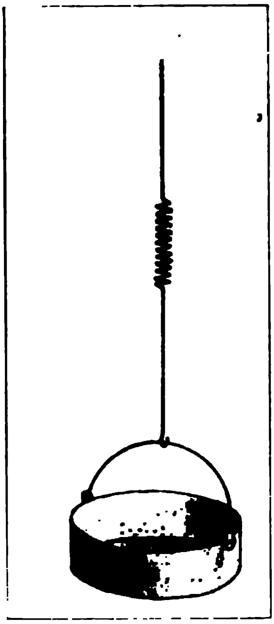
Two tubes are made so one will slide into the other to obtain diferent lengths ; place the tube over a candle or gas jet ; draw out the tubes until the proper length is found, when the flame will jump into vibration ; the result of the heated air rising rapidly from the flame causing the tube to emit a faint sound at first, which soon increases to a loud shriek.

SYMPATHETIC RESONANCE.

Take a slide trombone and produce a tone in front of a pipe organ and the proper pipe will choose the vibration of the tone and respond. Change the pitch and the pipe assumes silence and another will answer. Produce a tone from a low pitch gradually to a high pitch and all the pipes will respond and silence in regular succession as the tone passes by their individual pitch. If a singer stands near a piano and produces any musical sound that is on any of the musical pitches, the piano string that has the same pitch will answer and continue to sound as long as the singer utters the sound. Change the voice gradually to one note higher and as the voice leaves the pitch of the string it ceases to answer ; silence ensues until the voice approaches the next higher pitch, when the next string will gradually produce sound as the voice approaches the pitch of the string.

Stand in an empty room and produce a sound ; change the pitch gradually until the correct pitch is struck, when the room will seem to be full of sound. If the room is round, or has a spherical ceiling it will seem to be packed full of sound, causing a disagreeable sensation in the ears, similar to the sensation produced in the lungs when breathing air under pressure. The room will respond loud on its fundamental or natural

tone (*Do* in the major scale). It will also respond on its harmonics, the third and fifth (*Mi* and *Sol*), about one-half as loud. All rooms, pockets, etc., will respond when their proper pitch is struck.

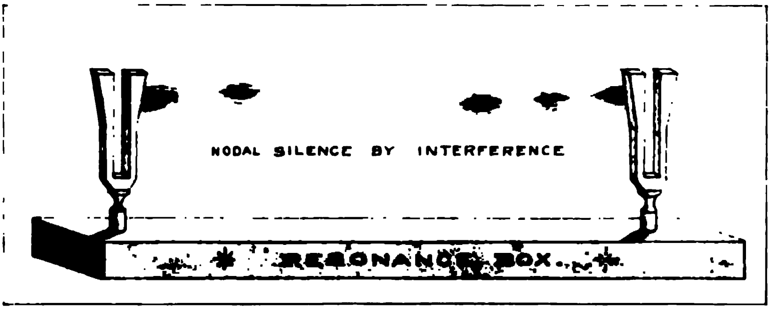


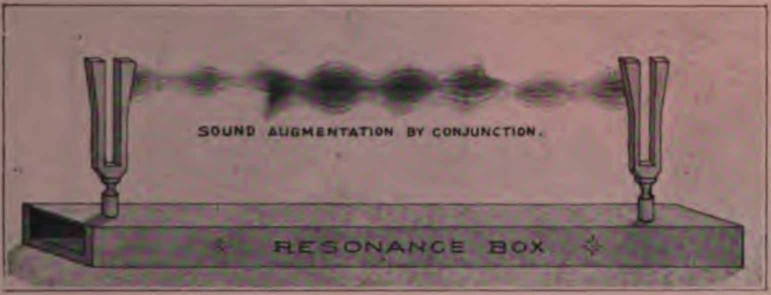
SYMPATHETIC NOISE.

The sound vibrations produced by a cornet will cause metals to rattle together, or against any hard substance. For example, a pair of shears will dance on the marble top of a table loud enough to be heard twenty feet or more; teaspoons in a glass holder make a disagreeable noise, as also tin pie pans, etc. Hang an eight-quart tin pail by a string from a hook in the ceiling, toss a few small lead shot or grains of coarse sand into the pail, and a blast from a cornet will cause them to dance a good imitation of a hailstorm.

PRIMARY RESONANCE.

If two tuning forks of the same pitch, size and form be stationed a proper distance apart to bring the condensation and rarefaction of their waves in perfect conjunction, the sound will be twice





as loud as emitted by one fork. If the forks be stationed proper distance apart to bring the condensation of one fork to correspond with the rarefaction of the other fork, silence will ensue.

NODAL RESONANCE—STATIONARY.

Take two tuning forks as illustrated in the last experiments, that produce sound waves two feet in length; set the forks at the right distance apart to bring the condensation of one fork in conjunction with the rarefaction of other fork; the result will be silence, or stationary resonance on a line between the forks, while on a line at right angles with the line of forks, sound will be heard in a subdued volume.

Vocal soloists very often experience great difficulty in developing and controlling tones on certain pitches. A singer strikes a familiar pitch to find that the voice is flat in pitch and poor in quality, which arises from the fact that the vocal chords are in a position or location that causes a condensation of the voice waves to coincide with the rarefactions of a returning sound wave from a resonance instrument, wall or pocket, thus nullifying the efforts of the singer. The voice flattens in pitch by the returning resonance wave, having a pitch a trifle lower, which, assisted by the lack of perfect confidence in nearly every singer, draws the voice over by sympathy in capillation. The singer allows the voice to be drawn over to the lower pitch, because the resonance of the instrument, wall or pocket increases the volume of sound as it approaches the pitch of the resonance. The quality of the voice is injured by the resonance, having a sound wave of a different amplitude, form and density. A change of location or position

of a foot or so, will generally bring the voice out of the interference of the resonance wave, and thereby restore it to its natural pitch and quality.

NODAL RESONANCE—TRAVELING.

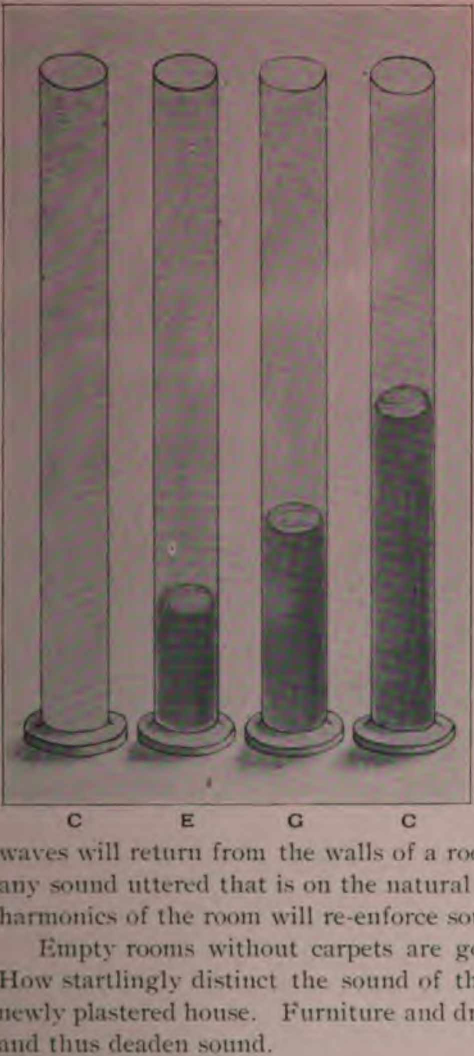
Change the tuning forks for one that will produce twenty-four sound waves to the second of time, and one that will produce twenty-five sound waves to the second. If the forks are set in

SINUOUS SOUND PULSATIONS IN TRAVELING INTERFERENCE

vibration they will produce, by the interference of their air waves, a sound that is a succession of pulsations or beats, connected by a softer or nodal sound. We find that with two forks, one having twenty-four and the other twenty-five air vibrations to the second of time, that a series of beats are formed by the different lengths of the waves that overlap, thus set the forks in vibration, when the fork with the twenty-four vibrations will overlap the other fork one twenty-fourth of a wave length, bringing one condensation and one rarefaction in conjunction at every twelfth vibration, causing partial silence (as in stationary resonance), and at every twenty-fourth vibration bringing the condensations together, which causes the vibrations to be twice the volume of one fork. Hence the sinuous sound wave. The above principle is nicely demonstrated in the "Vox Celeste" stop in an ordinary reed organ. The pulsating is produced by tuning two sets of reeds, one on a little higher pitch than the other; as the pitch of the reed rises the pulsations or beats increase in rapidity until they utter a harsh, grating, disagreeable sound.

COMPOUND RESONANCE.

If four glass tubes be arranged partly filled with water, they will respond to any of the four musical pitches indicated. For



C E G C

example, strike a tone on the the pitch of middle "C" with the voice and the tube middle "C" will instantly respond loudly. The octave "C" will answer with about one-half of the volume of tone of middle "C." The harmonics "E" and "G" will answer with about one-fourth the volume of tone that the fundamental responded with. Change the vowel tone to the pitch of "E" and the other three harmonic tubes will respond in the absence of their octave "E," with about one-third of the volume of the fundamental "E;" hence, compound resonance.

Two or more sound waves will return from the walls of a room and loudly re-enforce any sound uttered that is on the natural pitch of the room. The harmonics of the room will re-enforce sound considerably.

Empty rooms without carpets are good resounding pockets. How startlingly distinct the sound of the builder's hammer in a newly plastered house. Furniture and drapery stop the resonance and thus deaden sound.

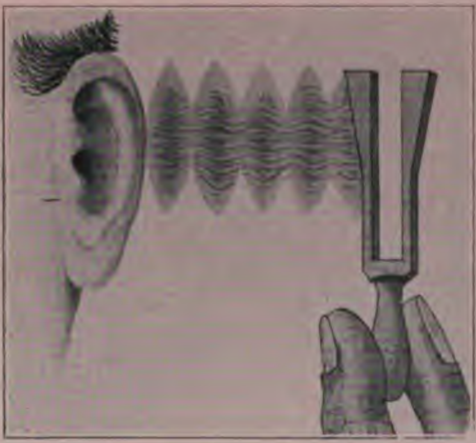
NOISE, SOUND AND TONE.

Any instrument, appliance or device so constructed that it will cause air to vibrate, will produce what is called noise, sound, or tone, according to its construction and application. Noise is the result of an irregular vibration of air, both in volume and rapidity,

being termed concussion or explosion. Sound is the result of periodical vibrations of air. Tone is produced the same as sound, but having a specific number of air vibrations to the second of time.

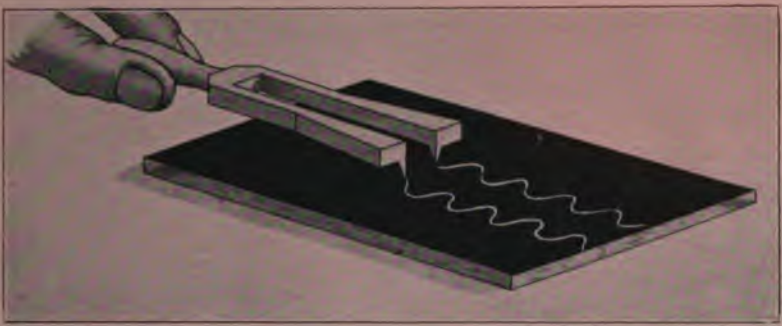
SOUND BY A TUNING FORK.

The simplest form of a sound-producing instrument is the tuning fork. By lightly tapping the fork against a hard substance, and holding it to the ear, a sound is heard, and also gentle puffs of air, as the fork is revolved by the handle between the thumb and finger. When the prongs of the fork are on a line towards the ear, the air waves are felt quite strongly. Touch the lobe of the ear very lightly with one prong, while in vibration, and a startling tickling, sensation is produced. Hold the fork by the handle between the teeth, and an indescribable sensation is conveyed to the ears by the conducting power of the bones of the jaws. If a large fork is used, each vibration can be distinctly felt by the nerves of the teeth. Hold the fork over a tube, or bottle of the proper size, and an audible sound is heard, the air in the tube re-enforcing the vibrations of the fork by resonance or sympathy. Set the handle of the fork on a marble table top, and an audible sound is heard, the marble re-enforcing the vibrations by its solidity.



SINUOUS WAVES ON GLASS.

The travel or amplitude of the vibrations made by the prongs of the tuning fork are nicely demonstrated by fastening a fine



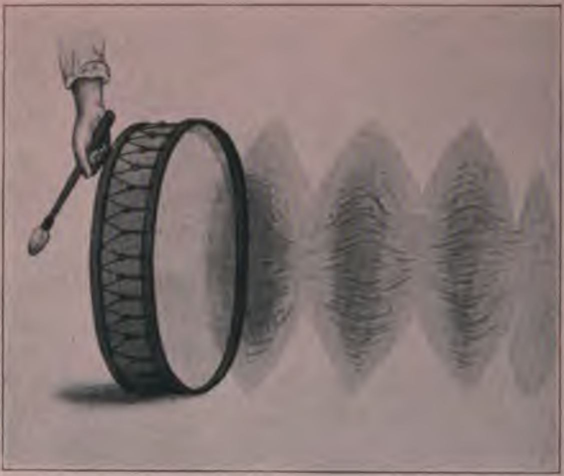
metal point to both prongs of the fork and drawing it lightly over a smoked glass while in vibration. A pair of serpentine lines are thus traced.

From many experiments by a vast number of persons of scientific research, with practically the same results, it is conceded that all sound is the result of the vibration or oscillation of the molecules of which the air is composed, combined with the sensation that is produced on the tympanum of the ear and its conductive power to the brain. In the above experiment we find that at each vibration of the tuning fork the prongs swing to and fro away from and towards each other. At each outward movement of the prongs the air is pushed forward and condensed in front of the prongs, and at each backward movement it is rarefied, forming a partial vacuum, thus producing a sound wave that is composed of one condensation and one rarefaction at each vibration. The length of the sound wave is measured from the centers of condensations in the same manner that we measure water waves from crest to crest. In water the molecules oscillate vertically, while in sound horizontally, or parallel to the line of their travel.

Air waves, in propagating sound, travel only very short distances, the molecules pushing or crowding against each other in such a manner their whole mass is condensed or rarefied in a series of periodical clusters and scattering groups of molecules, all being linked together in continuity, resulting in sound propagation when transmitted to, and analyzed by, the ear. The air waves, if they could be seen, would appear to be similar in movement to the long, heaving swell of the ocean, and not unlike the waves of a wheat field fanned by a gentle breeze.

INSTRUMENTS OF PROPAGATION.

Sound-producing instruments are divided into four general classes, viz.: Bombastic, Whistling, Stringendo and Reeds. Instruments that produce sound by concussion, as the drum, gong, bell and cymbals, are termed bombastic. The drummer strikes the drum-head a sharp blow, which forces it in towards



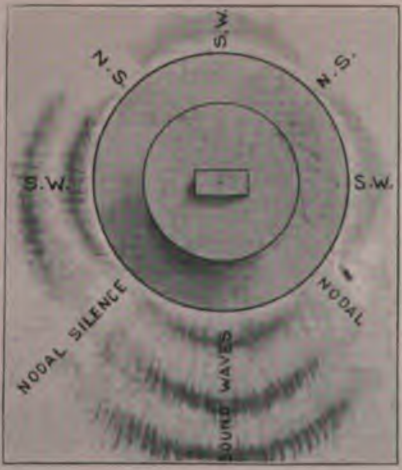
the opposite head; the distance is in proportion to the force of the blow struck, and the elasticity of the enclosed air, which with the mechanical assistance of the opposite head acts as a cushion or spring, causes the drumstick to rebound and the head to assume its former position. When the blow is struck the head is forced to one side in the line of the blow, pushing and condensing the air directly in front of it, and then the condensed air forces the head back to its former or natural position, producing air waves, whose shape in their cross-sections corresponds to a number of double convex lenses.

The gong produces sound nearly the same way as the drum, except that there is no enclosed air cushion to assist re-enforcement of vibration, the gong depending on its mechanical construction to regain its former position unassisted by an air cushion.

BELL VIBRATION.

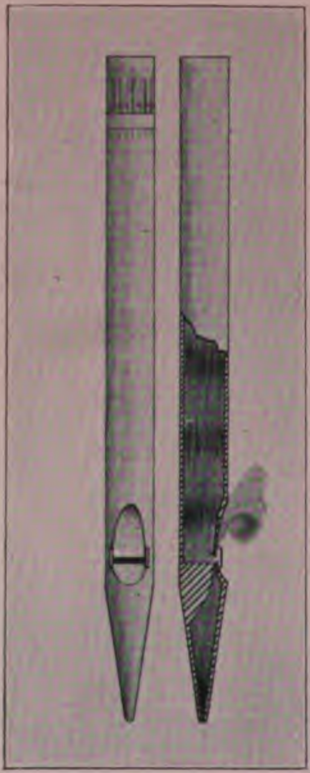
The bell produces sound by the clapper striking its sides and setting it in vibration in four segments, joined by nodal points,

each segment producing a primary wave in conjunction with its opposite segment, which, combined, gives a clear, ringing tone. At each stroke of the clapper the bell assumes an elliptical form parallel with the line of the stroke, and instantly assumes an opposite ellipse, hinging on the four nodal points. The four nodal points are found diagonal to the line of stroke, or by sifting fine sand over the entire outside surface of the bell. Strike the bell a sharp blow with the clapper and the vibrations will cause the sand to gather in four rows at or along the direction of the nodal lines, showing that the nodal lines remain stationary or silent.



SOUND BY CYMBALS.

The Cymbals produce sound vibrations by striking the edges together. Their vibrations are so irregular that they may more properly be termed noise or concussion vibrations. As taken alone they are devoid of nearly all properties of musical sound.



SOUND BY WHISTLING.

The best example of the whistling class of sound-producing instruments is the diapason pipe in the modern church organ.

To produce sound in the pipe the air is forced through the throat in a thin sheet and strikes the edge of the web, causing the air to flutter in a cylindrical motion, which it imparts to the enclosed column of air, thereby making sound waves to travel up and down the pipe in a regular order of succession, thus producing sound. The length of the pipe establishes the musical pitch of the sound.

In the flute and piccolo the pitch of the instrument is established by the performer forcing his breath and thus dividing the air column into vibrating segments having nodes.

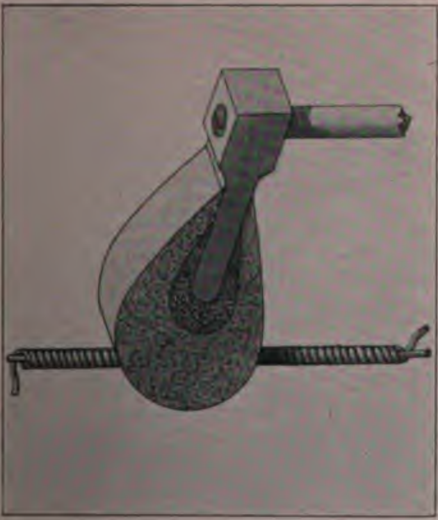
SOUND STRINGENDO.

As a demonstration of stringendo, stretch a stout string or a fine wire tightly from two pins. Force the string to one side and let it go, and a soft, twanging sound is produced, caused by the small ovoid cylinder of air set in vibration about the string. Stretch the string over box (same as guitar) and the enclosed air

in the box will re-enforce the air vibrated by the string ,and thus produce a rich musical tone. The pitch of the string is governed by the size, tension and length of string.

In the Violin the hair used in the bow, in its natural state, has an irregular series of barbs or teeth, similar to a carpenter's saw, which hook over the string and force it to one side until the tension of the string overcomes the friction or strength of the barb, when the string slips back on the bow in a succession of small jumps, the length of the jumps being governed by the size, tension and length of string used. Violin, Viola, Cello and all bow instruments are similar to the Violin in their method of sound propagation.

The string of the Piano is set in vibration by being forced out of position by a blow of a wooden hammer, having a face of thick soft felt, which bounds back instantly from the string, leaving it free to continue the vibrations.



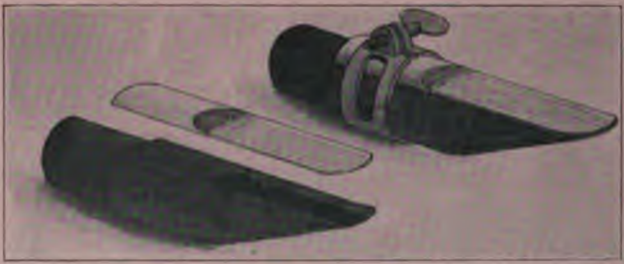
Harps, Guitars, Mandolins, etc., produce sound by having their strings pulled to one side with the fingers and let go, which gives a slightly twanging sound, unlike a Piano in smoothness.

The flat twanging sound of the Banjo is the result of the string having no enclosed air

pockets to re-enforce the tone, the instrument depending on the vibratory motion of the leather head of the Banjo for the quality of the sound.

REED SOUNDS.

A Clarionet produces sound by vibrating a column of air with a single reed set over a slot opening at the enclosed end of a hollow tube. The reed is thick at one end and tapers thin at the



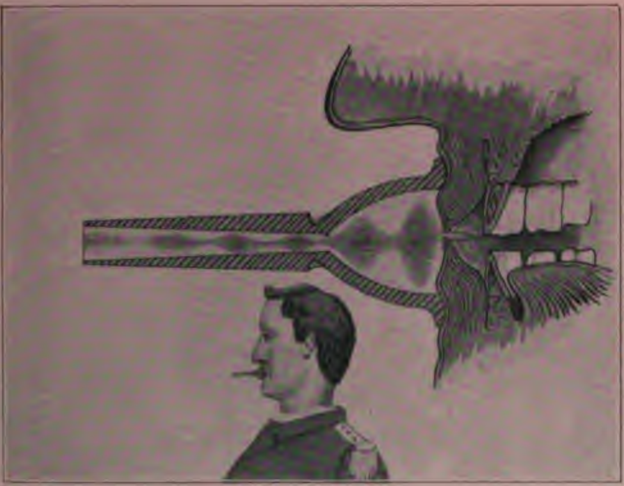
loose end. It is fastened to the tube by a flat circular band, leaving the thin end free to vibrate, which is done by forcing the air through the slot underneath the reed. The air causes the reed to flutter, closing and opening the slot alternately, making the columns of air to assume sound vibrations by the admission of air in small puffs.

The Organ, Melodeon, Accordion and Concertina produce sound by a long, thin, narrow metal reed, fastened firmly at one

end to a flat metal plate, having a slot opening directly under the reed, which vibrates to and fro through the opening, letting small puffs of air through at every vibration.

The Cornet and Horns give forth sound by the lips of the performer setting the enclosed column of air in vibration. The

lips are pressed against a conoid or concave-shaped funnel mouthpiece, having a small opening at the apex that connects with the tube that forms the instrument. The lips are pressed tight to-

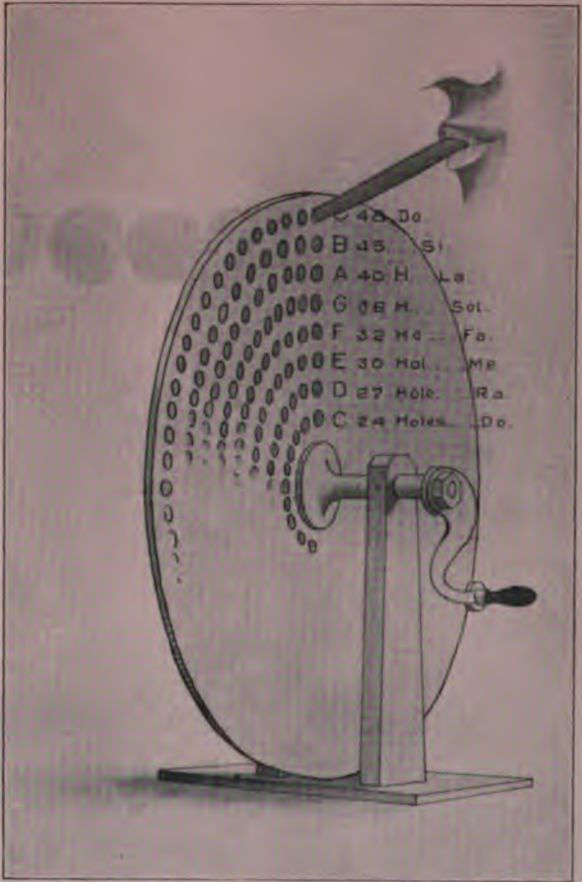


gether and also under tension lengthways, caused by the pressure against the mouthpiece. By forcing the air between the lips while in tension, they act as two reeds swinging to and fro and emitting small puffs, which cause the air column to vibrate; the stronger and greater the tension the higher the tone will be.

METHOD OF PROPAGATION.

If a circular metal disc, having a row of holes, be made to revolve rapidly on an axis and air forced through the holes by a tube or pipe, sound will be produced by the alternate opening and closing of the orifices, allowing the air to pass through the holes in a succession of uniform puffs. The rapidity of the puffs determine the pitch. As the number increases the pitch rises to a sharp, shrill sound. Slacken the speed and the pitch immediately falls. The greater the force of air used the louder the sound will be. Diminish the power and the sound drops to a gentle muse. We find that the outer series of holes in the disc has just twice the number of the inside row, hence we conclude that an octave higher has double the number of vibrations that

the next octave lower has, and that as sound waves increase in rapidity the pitch of the sound rises correspondingly.



If the disc has a series of eight rows of holes, having 24, 27, 30, 32, 36, 40, 45 and 48 holes respectively, and the disc is revolved with sufficient velocity to cause the 256 holes to pass the blow pipe in one second of time, the outside row will give the pitch of middle C on the piano. If the blow pipe be passed from the outer row of holes over each row in regular order to the inner row, eight different pitches will be given, corresponding to the major scale in music. The number of the vibrations corresponding to the different pitches between middle C and low C are: C 128, D, 144, E 160, F 170, G 192, A 214, B 240, C 256.

CHAPTER IV.

UNDER ordinary circumstances and the same conditions, all sound waves travel at practically the same velocity, although history recalls some instances where there were small variations in the velocity.

Station two hunters 1,090 feet apart on a fine, clear, cold day in the winter, when the air is still and when the thermometer registers at freezing point (32 degrees). Select a flat, open stretch of land or, what is better, a frozen river or lake. If a gun be discharged by one of the hunters, and the other *times* the report between the flash of the gun and arrival of the sound, by a stop watch, the watch will indicate one second of time for the travel of the sound.

The Strait of Gibraltar, at the junction with the Mediterranean Sea and the ocean, is ten miles in width. On the northern shore is situated the memorable British fortress, Gibraltar. On the southern shore is situated the town of Ceuta. On a clear evening, with the thermometer at about 32 degrees (freezing), the flash of the sunset gun fired at the fort of Gibraltar can be distinctly seen at Ceuta, while 48 seconds elapse before the sound is heard in Ceuta, or about 1,090 feet to each intervening second of time between the seeing of the flash and the arrival of the report.

WAVE LENGTHS.

We find, by the above experiments, that sound travels about 1,090 feet per second; therefore, if we divide the distance of one second's travel by the number of vibrations of a second, the quotient will be the length of wave. For example, the pitch of middle C on the piano has 256 vibrations to the second of time, which, divided into 1,090 feet, will give four feet and (nearly) four inches as the length of a sound wave on the pitch of C.

At each rise or fall of a degree in temperature the sound will vary about one foot in distance, increasing in velocity at rising

of temperature and retarding as the temperature falls. The change in the velocity is due to the heat changing the density of the air. The higher the temperature the greater the flexibility. All sounds, high or low, strong or weak, harsh or smooth, travel practically at the same rate of speed, and diminish in intensity inversely, as the square of the distance increases.

We hear a band, consisting of a dozen or more instruments, playing some familiar piece of music aboard a boat, one-half mile or more from the shore, yet the harmony and melody of all the different instruments are preserved the same as though heard in close proximity. The boom of a cannon and the snap of the fuse cap reach the ear at the same instant. The roar of the mighty Niagara travels no faster than the cricket's chirp or a sighing breeze. Sound travels more uniformly at night than by day, the air being more homogeneous and slightly denser.

TIMBRE.

Timbre is the form, quality and density of the sound wave, and their effects registered on the tympanum of the ear. The sounds are termed according to the sensation produced, as: Dead, Harsh, Cold, Rich, Warm, Pure, Live. The conditions and method of the propagation of sound waves which produce the different kinds of timbre are of several kinds or methods.

A sound wave is composed of a small company, group or band of traveling waves, starting from the same point or source and bound for the same destination. Under ordinary circumstances the group of travelers is composed of one large fundamental or leading wave, which is the basis or support to which the rest of the company cling to or follow—the fundamental by which the pitch is determined, as it has in its volume and density nearly always more than one-half of the sound waves of which it is a component part. Traveling in close conjunction with the fundamental are two small waves, termed major harmonics, whose combined volume and density is always less than that of the fundamental. One of the harmonics has a higher pitch than the fundamental—its pitch being one third above; while the other harmonic has a pitch one fourth below.

The harmonics are always in perfect tune in pitch with the fundamental and also with each other, but in nearly every sound-

propagating instrument the volume, form and density of the fundamental, by its predominating size and density, carries the volume of the sound wave, while the harmonics accompany the fundamental, giving it finish and resonance. The major harmonics, like the fundamental, each have two accompanying or secondary harmonics, which bear the same relation to their superiors that the major harmonics bear to the fundamental wave.

A DEAD SOUND is one that is composed entirely of the fundamental — a sound without resonance; a sound that stops instantly, the moment that propagation ceases; for example, the blow of a hammer against a piece of a marble, pebbles thrown against a window glass, the babble of a brook over its rocky bed, the hissing steam escaping from an engine, afford prominent examples of dead sounds.

HARSH SOUNDS are the result of the harmonics predominating in form and force over the fundamental. The apparent roughness or ridges of a sound or tone are caused by the harmonics re-enforcing each other at certain intervals, or when their waves are in conjunction, as in "Traveling Nodal Resonance"—sound in which only slight resonance is discerned.

COLD SOUND is a sound in which the fundamental is forced sufficiently to nearly drown out the harmonics.

RICH SOUND is a sound in which the fundamental and the harmonics are evenly balanced in form, volume and density.

WARM SOUND is a sound in which the fundamental and lower harmonic are evenly balanced in form, volume and density, while the higher harmonic is greatly reduced in all its proportion.

PURE SOUND is a sound in which the fundamental and harmonics are evenly balanced in form, volume and density; a sound that is not forced sufficiently to rupture the wave form; a sound that is smooth during its entire existence; one that does not wave or flutter, and is clean, clear cut, as the high note of a piccolo, or the open diapason pipe of a church organ.

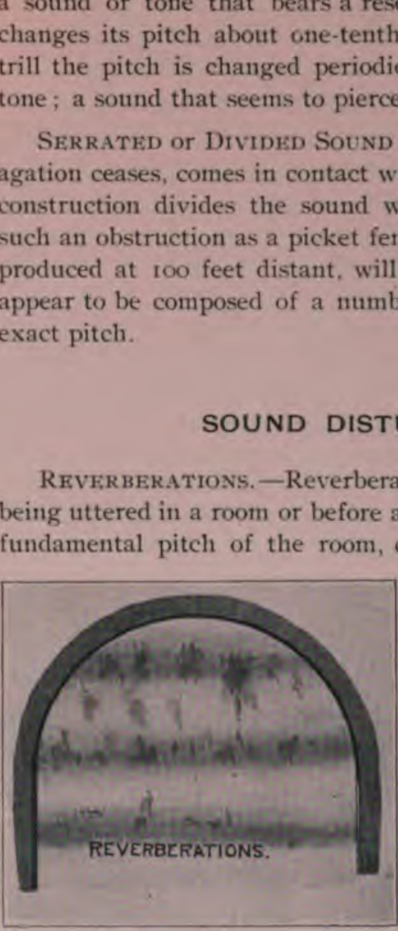
LIVE SOUND is a sound in which the fundamental and harmonics are in discord on pitch, but are in harmony in volume and density; a sound that has a rapid succession of periodical pulsations or swells, which increase and diminish the volume of the sound about 33 per cent. of its original or fundamental volume;

a sound or tone that bears a resemblance to a Trill in that it changes its pitch about one-tenth of a major step, while in the trill the pitch is changed periodically a minor step, or one-half tone; a sound that seems to pierce the ears to a painful degree.

SERRATED or DIVIDED SOUND is a sound that, after its propagation ceases, comes in contact with an obstruction which by its construction divides the sound wave into two or more parts; such an obstruction as a picket fence, which, if a sharp sound is produced at 100 feet distant, will give forth repetitions that will appear to be composed of a number of individual sounds on an exact pitch.

SOUND DISTURBANCES.

REVERBERATIONS.—Reverberation is the result of a sound being uttered in a room or before a cavity or sounding pocket, the fundamental pitch of the room, cavity or pocket being on the same pitch as that of the harmonics of the uttered sound, which re-enforces the harmonics in the regular numerical proportion, thus producing what is termed a live sound, as indicated by the preceding paragraph.



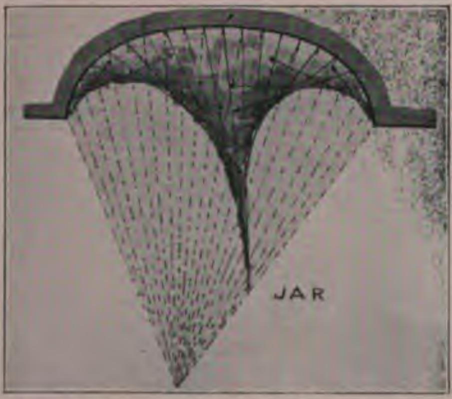
In large audience rooms, if a high, shrill tone be prolonged for some seconds, the room will appear to be filled with sound waves, which seem to pack into the ears, causing a very disagreeable sensation.

During sound utterance, the reverberations can be distinctly heard at the opposite side of room furthest from point of sound issue. If the room is large, and the sound is prolonged over or about five seconds, the reverberations will appear to be a separate sound or broken fragments of sound waves, having same pitch and quality as the other sound, but having a less volume. Reverberations are the result of only prolonged sounds, short sounds being treated as Crashes, Jars, etc.

SOUND HALO, or Reverberation, is the higher harmonics that accompany the fundamental during delicate tone shading—a fairy tone in unison with a primary; a smile of sound.

A CRASH is a blind echo and a primary wave in collision, without intervening silence; also a lapping collision between two returning sound waves at the junction angle of a room. The Crash will always extend the full length of the angle. In result, the Crash causes the voice of the orator to have the appearance of double vowels and no consonants, quite similar to two persons speaking at the same time. A stuttering or mockery of the vowel sounds, as if by some mysterious, unseen person or occult power. A Lapping Crash closes up like the slamming together of a large book—the angle corresponding to the back of the book.

A JAR is a returning sound wave from any circular concavity dome, or circular angle, focusing and lapping on a primary wave. Jars always focus at or near the generating point of the circular reflecting surface. When the Jar is the result of a sound wave returning from a continuous circle, corner or angle, the jar is named a wedge, after the form it assumes, a wedge being simply a jar which has a continuous focus or path. A wedge is similar to a double flutter with their backs or outsides joined together or united.



A FLUTTER is a primary sound wave in contact with a circular wall or ceiling when the point of sound issue is at the side of, or on a tangent to, the reflecting surface. The reflected wave coming in contact with a primary wave as it is reflected from the circular wall, causes it to assume a rolling or tumbling motion throughout its travel. The result is a sound re-enforcement to oratory or music similar to the prolonged and subdued rumble of distant, muttering thunder. The Flutter is the principle employed by organ manufacturers to produce sound with a pipe in the common church organ.

ECHOES are the result of a primary sound wave coming in contact with an obstruction, the nature and construction of which, combined with the air, causes the air, by its flexibility or elastic force, to rebound from the obstruction, changing the direction or path of the sound wave and reflecting it in another direction against other obstructions, or returning it directly back to the point of issue in propagation.

The distance the obstruction is from the center of propagation, and also the form, quality and density of the obstruction, determines the nature of the echoes, which are under three

general heads—Co-mingling or Resonance, Lapping or Reverberations, Returning or Repeating.

As the average human ear can distinguish sounds that are one-tenth of a second's duration (and sound at the average temperature travels at the rate of 1,100 feet velocity per second), then all obstructions or reflecting surfaces that are located nearer than about 60 feet of the point of sound propagation produce Resonance; all reflectors between 60 and 110 feet distant from point of sound issue produce Reverberations, Crashes, Jars, etc., while reflecting surfaces at a greater distance than 110 feet from point of propagation produce either

Simple, Multiple, Double or Triple Echoes;
Alternating, Multiple, Double or Triple Echoes;
Compound, Multiple, Double or Triple Echoes;
Complex, Multiple, Double or Triple Echoes.

A *Simple Echo* is a sound wave returning from the reflecting surface of an obstruction, with an intervening silence between the primary and the returning sound wave.

A *Simple Multiple Echo* is an echo in which the reflecting surface from the point of propagation returns one, two or more sounds or syllables; about 200 feet distance required for one syllable, 400 for two syllables, and so on. This kind of Echo is termed as Mono, Dis, Tris and Poly, according to the number of syllables returned.

A *Simple Double Echo* is the result of two different obstructions, each returning a sound wave at the same time to any given or known point.

A *Simple Triple Echo* is the returning of three different waves to any given point from three different obstructions at the same time.

An *Alternating Echo* is the result of a sound being uttered between two reflecting surfaces. Take, for example, a very wide river that has perpendicular banks of rocks about 1,000 feet apart. Utter a sharp, shrill blast on a bugle about 300 feet from

bank and an echo will be returned from both banks, alternately chasing each other in rythmical progression.

An *Alternating Multiple, Double or Triple Echo* operates the same on the alternating as on the simple echo.

A *Compound Echo* is the result of sound waves returning from two or more obstructions and focusing at two or more points at the same time.

A *Complex Echo* is two or more sound waves returning from different obstructions at different times and to different focal points.

CHAPTER V.

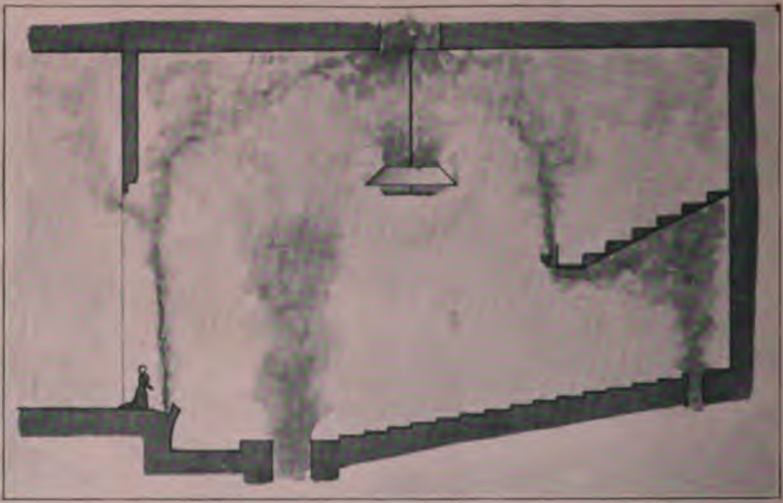
IN THIS Chapter the author will endeavor to demonstrate the air in relation to sound, which will treat of heating, ventilation and also the lighting apparatus. Atmospheric air in repose or silence, as in a tightly closed room or pocket, is composed of an even (level) homogeneity, having an evenly graduated density from the earth's surface, or the floor surface, perpendicularly. Like water in repose, it has a horizontal strata or grain similar to the grain of wood, this being caused by the difference in its density at different altitudes. The natural strata of air assists sound waves to travel horizontally, and the waves retain their volume on all levels with the point of their propagation until they die out by exhaustion. Sound waves issued at one level retain their full volume as they ascend to any other level; thus, a sound issued from a pulpit or rostrum appears louder to a person sitting in the gallery than to one sitting on the lower floor, level with the speaker or singer. The apparent increase in loudness to the gallery auditors is due to the air being lighter or less dense than on the lower level. Thus, in the reverse order, if we utter a sound at a high level the sound will appear to be much weaker in volume to a person sitting on a level lower than the point of sound issue. Therefore, for perfect sound propagation the air must be in perfect repose if the hearing is to be perfect. One of the great difficulties to overcome is the application of the mode of heating. There are, up to date, many kinds of heating apparatus that are nearly perfect from a heating standpoint, but total failures in regard to acoustics.

Any sound wave is deflected from its path by contact with a moving current of air in proportion to the density and velocity of the air wave. Hot air waves, undisturbed by outside conditions, rise and form ascending currents; cold waves, under like circumstances, settle .and produce descending currents. When the outdoor air is under motion, say, for example, blowing from the west toward the east at a velocity of 30 miles an hour, the

air in an audience room assumes the same direction of travel as the outdoor air, and the velocity varies in accordance with the number of openings exposed to wind travel. With all the windows and doors closed tight, the air will travel at a rate of speed of from one-fifteenth to one-tenth of outdoor air; while with all windows and doors open it will exceed one-half of the outdoor velocity. The air of an audience room thus disturbed by the wind is termed draught, while heat or cold disturbances are termed currents.

HEATING.

If a speech be delivered from a platform to persons standing about fifty feet from the speaker, and there is located a hot-air floor-register of four feet diameter on a line between the speaker

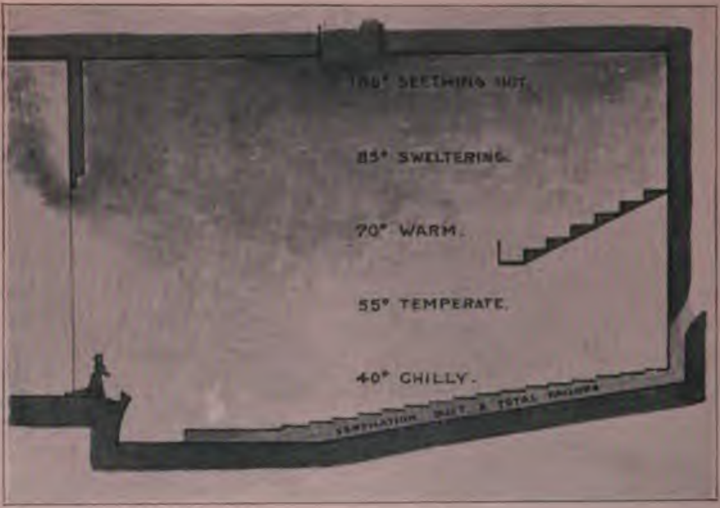


and the listeners, the sound wave as it issues will come in contact in its travel with the ascending current column of hot air, which will reflect a portion of its volume back to the point of utterance, deflect a portion out of its path, absorb a portion by carrying it upwards, and leave only a small portion to pass through the heated column of air to the listeners. These effects are due to the column of hot air being composed of a perpendicular strata or grain, which is of a fibrous nature, not unlike the grain of a

piece of tough, curly-grained wood. An air current thrown or projected on a white screen by a magic lantern has almost precisely the appearance of a boiling, seething river or creek. The Niagara River, just above the Upper Suspension Bridge, is a fine illustration of the current principle, only that the heat current has a greater velocity. The sound that reaches the ear of the listener is only the portion that, by its flexibility, dodges through between the crack-like openings of the heated column of air. If the singer utter and prolong a tone for some moments it will appear to the listener to be of an irregular volume, having a wobbling movement, like a crooked, gnarly root or limb of a tree. If a hot-air floor register be located in a narrow corridor, and a sound wave be uttered at one end of the corridor, the hot-air column will so disturb the sound wave that all language will be entirely nullified; the heat column mixing or jumbling the vowels and consonants beyond recognition, leaving the sound wave in broken form to dodge through the openings in the heat column to the listener, devoid of all articulation. Thus it is plain to be seen that it is improper construction to admit, distribute or agitate hot air by any manner or means to an audience room in large quantities between a speaker or singer and an audience. If circumstances compel the supplying of hot air in large quantities, supply along the side and rear walls, distributing the supply as evenly as possible along the entire wall space. The center of the room will be warm enough in the coldest weather if the walls are heated. There is also a great objection to heating at the wall surface where an audience room has a gallery around it, as the hot air passes out from under the gallery and, ascending in a thin sheet or curtain in front of it, encloses the gallery auditors in a space behind a curtain of hot air. A better way, where this method of heating is employed, is to build narrow, long slot-like openings up through the gallery floor where the floor joins the outside wall. This will remove the hot-air curtain at the gallery front.

HEATING THROUGH CEILING.

Some heating engineers advocate hot-air supply through the ceiling, this method being considered by some as an improvement on the above mode of heating. But, in supplying heated air



from the ceiling, the air must be forced down, as it is contrary to the natural travel of heat; thus, the top or gallery portion of the audience room is sweltering hot, while it is disagreeably chilly on the lower floor. The heated air only descends as the air at the top of the room becomes denser than in its natural state,' while on the main floor the air is too rarefied for easy respiration.

In the ceiling method, all the impure air is retained in the room and forced to descend with the heated air until the floor is reached, and then it is only partially withdrawn through ventilating shafts, the latter being almost total failures.

If ventilators are inserted at or near the ceilings for the escape of lighter gases, the hot air instantly appropriates this avenue of escape to the retention of the foul air.

If ventilators be used at or near the ceilings, large enough to permit all the gas to escape, the hot air will likewise all escape by the same route, leaving the lower part of the room in a temperature bordering on zero.

Some engineers resort to the use of powerful suction fans to draw the heated air down from the ceiling and out through the vents at or near the floor. In a very few instances this method has worked quite satisfactorily, but in a very great majority of cases it is a flat failure. In cases where the fans *do* succeed in

removing the impure air they do so at a loss of density, thus making the respiration of the audience wearisome for lack of oxygen in sufficient quantities to promote healthy, free and lively respiration. The denser the air up to a certain limit the better for comfort and good acoustics; as the denser the atmosphere, when dry, the easier sound waves are propagated by a speaker, singer or an instrument, and the fuller the sound will be when received by a listener.

It should be the aim of every heating engineer to construct the heating apparatus in an audience room in such a manner that in its working it will have the effect of creating the very least possible disturbance in the way of currents, draughts or uneven homogeneity. The difficulties to overcome for a successful setting of heating apparatus are many; but if the following principles are carried out they will enable an engineer to so construct the heating apparatus of a building that it will, in nearly every case, insure a remedy and remove any and all of the above bad effects to a degree of perfection heretofore unthought of, making a room, to all intents and purposes, practically perfect for hearing, respiration and temperature, and also thorough in ventilation.

CHAPTER VI.

AS HEATED air rises at a given velocity for each degree of temperature, so also does cold air descend at or nearly the same velocity under like conditions. Human life will not exist for a period of more than 48 hours, if unaided by artificial heat, at a temperature of 32 degrees, or the freezing point. Human life will also not exist for any length of time at a temperature of 100 degrees or over without resorting to some cooling method. By taking the difference between the two extremes of temperature that form the boundary line of life, we find that 66 degrees of temperature is the average. This is the most healthful and also the most universally agreeable temperature to nearly all persons in repose, although as low as 63 degrees is sufficient for persons during moderate or violent exercise, a great deal depending on the physical condition of the participants. Knowing, then, that a temperature of 66 degrees is the most perfect for comfort, as also for Acoustics, it should be the heating engineer's main object to introduce the heating apparatus in such manner that it will constantly maintain an even temperature over the entire room space without causing or sustaining any air disturbances in the way of draughts, currents, etc.

AIR SUPPLY.

As all heated air rises by natural laws, then to follow the law introduce all heated air at the lowest level ; up through the floor is the best. Cold air by natural law always descends, then to follow the law supply the cold air from the highest level ; through the ceiling is the best—no other place is as good. Now, if a cubic foot of air at 66 degrees be admitted at the ceiling and also at the same time through the floor there will be no bad effect. But if the air at the ceiling is at a temperature of 40 instead of 66 degrees (for example) it will at once descend to the floor, distributing itself evenly the entire length of its path in its

descent, without forming a downward current of air. Now, if the air at the floor be heated to 92 degrees before admitted to the room, or as many degrees above the normal (66 degrees) as 40 is below the normal, the heated air will at once ascend to the ceiling at the same velocity the cold air descended to the floor. This result is so plain that it does not admit of an argument; for both downward and upward currents by common consent will meet and entirely absorb each other as naturally as milk and water will mix. The unified or absorbed currents will give an even temperature over the entire length of their paths equal to the mean or average difference, which in this example will be 66 or the normal temperature.

QUANTITY OF AIR SUPPLY.

Among the countless heating appliances on the market, it is found that the general average of heated air supplied by the various methods employed is about 200 degrees of heat at the point of admission to audience rooms.

These tests were made principally with the indirect system of supply—hot-air furnaces, steam radiators and hot-water radiators being considered on the same basis of experiment in calculation. It is found that with heat at an average of about 200 degrees the proportion of the supply of heat and cold is directly in proportion to the temperature of the two sources of supply. With the heat at 200 degrees and the outdoor air at say (for example) 40 degrees, we find by mathematical proportion the following rule will give the exact amount of cold air to be admitted to an audience room that will nullify the hot air and bring the temperature to the normal of 66 degrees.

RULE.—Subtract 66 degrees, the normal temperature, from 200 degrees, the temperature of the hot air admitted to the room. Divide the remainder (134 degrees of heat) by the number of degrees the cold air is below the normal (66), which, in the preceeding example, is assumed to be 40 degrees below the normal. Therefore, we find that 26 into 134 equals about 5.16 times; or, in other words, for every cubic foot of hot air admitted to the room at 200 degrees there must be admitted 5.16 cubic feet of cold air at 40 degrees, in order to bring the average temperature to 66 degrees, or normal temperature.

HEATING AT 200°.

	☞ THERMOMETER.	☞ DEGREES BELOW THE NORMAL.	☞ CUBIC FT. COLD AIR TO EACH FT. HOT AIR AT 200°.
LIFE LIMIT.	100		
	95		
	90		
	85		
	80		
	75		
	70		
NORMAL.	66	NO HEAT USED	
	60	6	22.33
	55	11	12.18
	50	16	8.37
	45	21	6.38
	40	26	5.15
	35	31	4.32
LIFE LIMIT.	32	34	3.94
	25	41	3.27
	20	46	2.91
	15	51	2.63
	10	56	2.30
	5	61	2 20
ZERO.		66	2.03

WINTER WEATHER.

Artificial Heating vs. Natural Cold Air.

(No. 1.)

COOLING AT 32°.

	☞ THERMOMETER.	NUMBER OF DEGREES ABOVE THE NORMAL. ☞	NUMBER OF CUBIC FT. OF COLD AIR AT 32° ADMITTED AT THE DIFFERENT TEMPERATURES. ☞
LIFE LIMIT.	100	34	1.00
	95	29	.85
	90	24	.70
	85	19	.55
	80	14	.44
	75	9	.23
	70	4	.12
NORMAL.	66	NO COLD AIR USED.	
	60		
	55		
	50		
	45		
	40		
	35		
LIFE LIMIT.	32		
	25		
	20		
	15		
	10		
	5		
ZERO.			

SUMMER WEATHER.

Artificial Cold Air vs. Natural Warm Air.

(No. 2.)

In diagram No. 1, on the opposite page, the figures in the left hand column represent the degrees as registered by the ordinary thermometer. Figures on the right hand side indicate the number of cubic feet and decimals of a foot of cold air to be admitted at the different temperatures for each and every cubic foot of hot air at 200 degrees to produce the normal temperature of 66 degrees. The center column represents the number of degrees below the normal. This diagram is intended to illustrate the use of artificial heat with or in conjunction with cooler air in its natural state, all heat being stopped when the temperature of the outdoor air rises to the normal temperature of 66 degrees.

In diagram No. 2 the object is to demonstrate the proportionate use of artificial cold air with and in conjunction with air in its natural state when it has risen above the normal temperature and requires cooling.

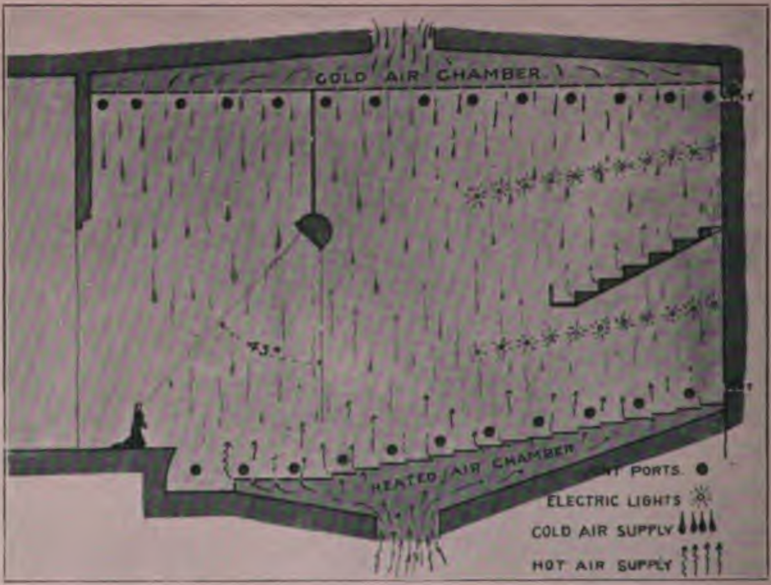
In heating, we assumed 200 degrees as the average temperature of applied heated air. Therefore, in cooling, we assume air at a temperature that is produced by passing air over or through ice, or 32 degrees (the freezing point of water), for which there are many mechanical methods now in use.

To ascertain the amount of cold air required at 32 degrees to lower air of a higher temperature to the normal temperature: Subtract 32 degrees from the normal temperature of 66 and divide the remainder, 34 degrees, into the number of degrees above the normal, and the quotient will be the number of cubic feet of cold air to be admitted at 32 degrees to bring the higher temperature down to the normal. Thus, if the air in an audience room is at 80 degrees, or 14 degrees above the normal, we divide 14 degrees above the normal by the difference between the normal and the cold air (which is 34 degrees), and the quotient, 0.44 cubic feet of air, is what will be required for each foot of warm air to lower the warm air to the normal temperature of 66 degrees.

METHOD OF SUPPLY.

Nature, guided by the Infinite hand in supplying man's wants, does so in such a manner as to bring the best results to the greatest number of persons and things. The rain falls in

tiny drops, and not by the cubic yard. Light reaches the earth in infinitely small rays—too small to be seen by the unaided eye. Air is so delicate in its touch that the pollen of the lily is not disturbed or the scent of the rose wafted away. Can man improve on the divine law of distribution? If not, then the only way that seems proper and correct in the method of supplying hot and cold air to an audience room that will leave the air in the room in a state of perfect quietude or equilibrium, with an even homogeneity, is to supply and admit the heated air up through the floor, over its entire space, through a vast number



of small openings and not by the cubic yard, as is generally the way with most heating engineers. Thus admitted, the air will rise toward the ceiling as silently and gently as a morning mist rises from a brook or pond, leaving the audience room, from a heating standpoint, perfect in acoustics and hygienics, and so comfortable that it will afford the auditors perfect enjoyment of the entertainment.

As a shower on a sultry day lowers the temperature, so will cold air cool a room if admitted in very small quantities through small openings over the entire ceiling. By this method the

heated air will be imperceptibly lowered down to the natural temperature of 66 degrees without disturbing the strata of the air by draughts or currents.

In a room heated or cooled as above described, there being no draughts or conflicting air currents to be overcome, the ventilation is a very easy problem to solve as compared to the present mode of heating. By the method of heating and cooling we have just described the gases, left undisturbed, will by the natural laws of equilibrium assume their normal altitude or location. The lighter nitrogen gases will locate at the highest part of the room close to the ceiling, while the heavier, or carbonic acid gases, and also all floating particles of organic matter, in both dust and gaseous form, will descend to an assumed repose at or near the floor. With the gases thus located, they can be excluded from the room by the ordinary ventilator, which in the common method of heating is worse than a failure.

Locate vents through the ceiling to let the lighter or ceiling gases escape, as the cold air that is admitted at the ceiling descends by gravity and will not escape through the open gas vents under any conditions whatever.

Likewise, vents located at the floor will allow all heavy gases and organic matter to freely escape without letting one particle of heated air escape, as heat will not travel down through a vent without mechanical assistance.

Thus it is seen that the vents work in such manner as to constantly improve the conditions of the air without having an objectionable feature. Under ordinary conditions the vents require no mechanical assistance of any kind, as their work or operation is governed entirely by natural laws.

HEAT DIRECT VERSUS INDIRECT.

As to a choice between a hot-air furnace, a steam or hot-water radiator, I have no argument or opinion to advance, each principle being correct of its kind. The trouble or faults lie with the manner of admission and distribution, and not with the method used of producing heated air.

Indirect admission of hot or cold air to a room is scientifically correct, and practically so in all its phases.

Direct heat applied to the air of an audience room is, in my judgment, nearing the boundary line of what may be properly termed criminal ignorance. It certainly displays a great lack of knowledge of the fundamental laws of hygienics, leaving acoustics out of consideration.

Direct heat applied to air is analogous to having the vegetable cook boil in the same water, day, week and month, all the vegetables used in the family, never changing the water, only filling up the kettle when the water is too low to cover the vegetables. In like manner, the direct heat simply stirs up the foul gases by the currents produced.

The result of direct heat is bad from an acoustical standpoint, as it augments the heat currents and forms many new ones. In direct heating the heated air rises to the ceiling, forming a partial vacuum at the foot of heat current, or near the register or radiator, while the cooler surrounding air of the room rushes down and fills up the vacuum, thus forming an upward and also at the same time a downward current of air. The result is the downward current surrounds and envelops the up current in a shell-like case, and the entire air of the audience room is one mass of slowly boiling and rolling air currents, utterly unfit for healthy respiration, and completely devoid of all acoustic properties.

The method used in the admission of air to an audience room is capable of such a vast range of mechanical applications that it would be practically impossible to devise a mode of admission that would be or could be made applicable and satisfactory even in a majority of cases, the requirements and conditions being so vastly different in various localities. Nevertheless, the following system will cover the entire principle of admission required for any locality or condition, subject to the mechanical requirements of each particular case :

First.—The heated air can be admitted to the room up through three-quarter-inch holes, bored about six or eight inches apart, over the entire floor space. A slight objection to this is that the sweepings will drop through the holes.

Second—Where an audience-room floor is built on an incline, with a series of low and broad steps (stair fashion) to set the rows of seats upon, admit the heated air out under the nosing of

each step through an opening not to exceed one-quarter of an inch wide, but the entire length of every step on the sides and rear half of the room. This applies only to the main floor. When an audience room has two or more galleries, it would be advisable to admit heated air along the side and rear walls of the lower gallery only, leaving narrow, slot-like openings through the top gallery floor, at the wall line, for the passage of the heated air to the top of the house without passing out from under the gallery and forming a sheet current of hot air between the gallery auditors and the rostrum. This same system should govern the cold air admission through the ceiling, as cold air is governed by the same laws of philosophy as heated air.

HEATED AIR STORAGE.

Build under the auditorium a room as large as possible—the larger the better; even if it is the full size of the audience room.

This room should be built of brick, plastered smooth, and should be wind, dust and water tight. The floor should be cemented. The floor timbers of the auditorium should be left exposed or open into the storage room. The floor timbers should be planed in order to prevent their catching dust.

The entire side walls and ceilings of the storage house should be coated over with a heavy covering of quick lime paint, as lime is a great disinfectant and also a purifier of air. Spiders and other insects dislike and shun lime-covered walls in choosing a homestead.

Connect the storage room at least at four points of the compass with the outdoor air, using heavy, bright tin for air ducts. Provide the ducts with graduated damper at the outdoor or inlet end of the duct, that the fresh air admission may be regulated to suit the cold air supply needed to maintain the temperature of the audience room at the normal temperature of 66 degrees.

Where the conditions will not admit of a storage room being built under the audience room (as described above), then hang a false ceiling from the joists under the auditorium. The ceiling should be built so it would be about six inches below the bottom of the floor joists at sides of the room, and pitching or slanting

down to the point of heated air supply, like a hopper in a grist mill, or an inverted hip roof of a house. The false ceiling should have a smooth construction on the inside or top. If lined with bright tin the heating properties will be greatly improved, the tin being a non-absorbent of heat, and it will also promote the travel of the heated air by its frictionless surface. The heated air should be admitted up through the false ceiling in at least four different points of the compass (six points are better when possible) for the reason that on a cold day, with a strong wind blowing outdoors, it is practically impossible to force hot air to travel in a pipe against the direction of the prevailing wind, while the heated air will, in a reverse order of motion, endeavor to all escape through the pipe that leads in the direction of the wind's travel. Heated air should never in any case be admitted directly up into either the storage room or through the false ceiling, as it will have a tendency to concentrate the hot air supply, instead of distributing it over a large floor space when it is admitted to an audience room.

STEAM OR HOT WATER HEATING.

When steam or hot water is used as a medium of propagating or producing hot air for warming an audience room, the best method of construction is to hang the circulating pipes from the ceiling of the storage room. The pipes should cover the entire ceiling space of the storage room. Fit up the piping so that there will not be more than one inch between the pipes. All pipes should be less than five feet in length, and be fitted with or into a manifold, and not by the continuous or serpentine method. If the audience room is very large and high, and one layer or tier of pipe is insufficient to produce the required amount of heated air to maintain a normal temperature of 66 degrees during the coldest weather, then another tier or layer of pipes should be laid in such a manner that the second tier of pipes will come directly over the parallel spaces between the first tier of pipes. Equally good or better results may be obtained by laying the top tier of pipes crosswise, and not over one inch above the lower tier. The crosswise manner gives more rapid travel

of heated air, while the parallel method gives the greatest quantity of heated air.

The ordinary method of forcing air through a box which contains coils of steam or hot water pipes is correct when considered from a heating standpoint only, but when used in heating an auditorium where Acoustics are required this method is in most cases a flat failure, as it issues the heated air from the generator in a boiling current by the cubic yard, which is very little if any better than the hot-air floor register described in a previous chapter. Where it is necessary to use the box generator, it should be so constructed as to issue the heated air as far below the ceiling of the storage room as possible, in order that the heated air may be distributed over as large a ceiling space as possible before it finds admittance to the audience room. Never in any case conduct the air directly from the generator to the audience room in bulk, as it would thus be a vigorous rival of the floor register or the hot air furnace.

When the box generator is used it should be located as close to the floor of the storage room as possible. Build over the escape port of the box generator a canopy not less than ten feet in diameter, to spread or distribute the escaping hot air before it leaves the generator. Make the canopy the shape of an inverted Japanese umbrella, or similar to an umbrella hung up to the ceiling by the handle with the top downward. The lower the canopy the better it will distribute the heated air.

HOT AIR FURNACE.

When the method of heating employed is by the hot-air furnace, it is a good plan to build the furnace in the outside walls of the storage room and cause the cold air supply to pass around the furnace and out at the opposite side instead of the top, as in the ordinary way, the object being to keep the heated air as low as possible as it enters the storage room. Hang the canopy over the supply port to the auditorium the same as suggested for the steam generator. An equally good way of setting up a hot-air furnace is to locate it a little out of the center of the storage room towards the direction of the prevailing winds in the winter season,

as the wind outdoors will cause the heated air to change location in direction of the wind's travel or path. When one furnace will not supply enough heated air without forcing the furnace, then set up another furnace, as air brought in contact with a highly-heated surface has its life-sustaining quality injured by the burning and destroying of the oxygen of the air. Two furnaces with a low fire are very much better in all cases than one furnace with a roaring hot fire, as two furnaces with low fires will give a large supply of heated air at a healthful temperature, while a furnace with a very hot fire will supply only a small quantity of highly-heated air in a very unhealthful condition, besides having a great tendency to form heat currents to the detriment of Acoustics. Furnaces set in the storage room will work quite satisfactorily without any casing. But if required to enclose the furnace, do so by encircling the furnace with a band of sheet iron, not nearer than 8 inches to the fire-pot; leave the casing entirely open at both bottom and top of the furnace; hang metal canopy not less than ten feet in diameter over top of furnace, as described for steam generator; carry casing to about 22 inches of the floor, and fit a collar to bottom of casing about 18 inches wide. The collar should slant out and down towards the floor at an angle of about 45 degrees, in order to promote the draught of cold air up and behind or inside the casing. The outer or lower rim of the collar should be about six inches above the floor. When it is not feasible to use a canopy over the hot air supply, then enclose the top of the furnace, or top of supply of steam or hot water generator, and connect with bright tin pipes, covered with asbestos felt coverings. Make the pipes about 12 inches in diameter at the supply or inlet at the furnace. Taper the pipes their entire length to about three inches in diameter at the end farthest from the furnace or generator. Give the pipe all the pitch possible to hasten the travel of the air. Begin at the supply or large end of the pipe, and punch a row of holes along the center line of the top, about two inches apart, the entire length of the pipe. Holes at large end should be about one-half inch in diameter and gradually increase in size the entire length of pipe to about two inches in diameter at the small or farthest end of the pipe from the furnace. Leave the small end of the pipe open and turned up with an elbow.

CHAPTER VII.

LIGHTING APPARATUS VERSUS ACOUSTICS.

IN TAKING up the subject of lighting apparatus, the author will endeavor to treat on the subject both as regards to direct and indirect lighting, with specific reference to Acoustics. Light may be properly divided into two general classes or kinds, according to the mode of propagation, issue and distribution: Solar light, or that propagated by the sun or other heavenly bodies in space: and artificial or mechanical light, or light that is the direct result of the application and combination of the laws of mechanics and chemistry.

Mechanical light is divided into a number of different kinds, two of which will be used as examples in the illumination of audience rooms, viz.: Lights that are produced as a result of combustion or burning, and light that is the result of incandescence or electric phosphorescence. We will demonstrate by the candle and coal-oil lamp, both material and manufactured, as examples of light due to the result of combustion, and the incandescent and arc light as the productions of electric phosphorescence.

The direct effect that light has on the Acoustics of an audience room is due to the relative amount of heat distributed and the prevention of the formation of heat currents similar to those of the hot air furnace. Tests have been made with the standard thermometer, held for five minutes at a time in different places and locations, as to the amount of heat emitted from the different kinds of lights now under consideration.

Lights that are enclosed in cylinders, like lamp chimneys (especially lamps with the circular burner, as the student's lamp or Rochester lamp), emit a greater quantity of heated air at a slightly higher temperature than lights exposed. Gas jets also, when they have globes around them that are open at the top and

bottom, emit a greater quantity of heated air than exposed lights, as the heated air in the enclosed cylinder operates as a chimney, having a strong draught; consequently, a light enclosed in a cylinder will emit from two to ten times as much heated air as the light burning open and exposed directly to the surrounding air.

Under ordinary conditions a candle, lamp or gas burner, having the same sized flame, will give practically the same temperature if measured at the same distance from the light either on the side or at the top of the chimney. By further test it was found that the degree of heat emitted by the light at the side, or on a level with the center of the light, is about one-twelfth of the heat above the light. By holding the thermometer one foot above the light and also at a point one inch from the side of the light the thermometer registered the same number of degrees of temperature in both locations. Tests made with a 16-candle-power incandescent electric light gave a temperature at one inch above the globe equal to the temperature at one foot above a three-foot gas burner, or, in other words, the gas flame emitted from 140 to 160 times as much heated air as the electric light did. At about 16 inches above the electric light the thermometer showed no change or rise in temperature.

The results of tests made with the arc electric light of 2,000-candle-power, the same as used for the lighting of streets, are practically the same, according to the amount of light emitted.

Thus it is plain to be seen that lights that are the result of combustion, of which gas is the principal one in use in nearly all auditoriums, when used for illuminating purposes must, by the natural law of heated air, produce draughts, currents, etc., to the great injury of the acoustic properties of the room. By numerous tests and comparisons it has been found that the lighting of an auditorium with gas is more injurious to its acoustics than any heating apparatus now in use, especially in its effects on the auditors in the gallery. The amount of heated air thrown off by a common four-foot gas jet is equal to about one square foot of heat-generating surface of any of the modern hot-air or steam-heating apparatus on the market. A gas chandelier with six or eight four-foot burners will give more heat than a steam radiator that has a heating surface of 25 or 30

square feet. The common, circular chandelier with a radius of three feet, generally known as the "Frink" reflector, will produce from 30 to 75 per cent. more heated air than any other heating apparatus.

Therefore, in good and perfect acoustics, gas should never be used for illuminating purposes, as it is hardly possible to arrange the lights in such a manner as to afford good, clear vision and at the same time retain acoustic qualities that will enable a person to distinguish over one half of the vowel sounds while occupying a seat on the main floor. The bad hearing in most cases, except first gallery, greatly increases the higher in the room one occupies a seat; as over every gas burner there is a miniature heat current ascending ceilingward, while over the main chandelier there is a vast, boiling, seething, heated air current, equal to or greater than the hot-air floor registers. Its bad effects are not so noticeable as the floor register, simply because it is above and out of the line of vision and hearing of the audience and the speaker or singer on the rostrum; yet it keeps the air in the higher part of the room in a constant boiling movement, which is a great aid in causing those disagreeable reverberations so common in high rooms, especially where there are circular corners in the junction of the rear angles of the room or the parts farthest from the rostrum.

Gas jets located along or projecting out from the gallery will form heated air currents about one foot in diameter above each burner; therefore, if they be located one foot apart, their individual currents will blend and completely shut off acoustic communication with the rostrum or stage and the gallery auditors with a current of heated air about one foot thick at its base, or on a level with a line of vision and hearing, which gradually thickens and distributes as it rises ceilingward. Where the conditions require light on the gallery front it is best to group them as far apart as possible, using large burners and as few in number as will be sufficient to meet the requirements. The farther apart the groups are located the less will be the obstruction, and the greater will be the intervening field of currentless air left for hearing.

If gas jets be located on the outside walls, under the gallery, they will form a sheet current of heated air similar to lights located along a gallery front, except that the heat currents from

the wall lights will be more evenly distributed along the entire front by their passage along the gallery ceiling and escape from out and under it. Lights should not be used under the gallery or any projection where there are listeners above and behind the travel of the escaping heated air curtain or current.

Lights under projections should be connected with or have some kind of vents just over them. Where no vent shaft is possible, then openings should be cut up through the gallery ceiling, close to the wall. A two-inch tin tube, with an inverted funnel-shaped hood, over a gas burner will carry off the heat generated by a half dozen ordinary gas burners, providing the funnel is large enough in diameter to hood, umbrella fashion, the heated air currents. The hood or funnel should not be over twelve inches above the lights, and ought to project out over each burner at least four inches for the heated air to be entirely carried up through the funnel escape port.

Gas burners may be located along the rear half of side walls and the entire rear walls above the gallery without any particular damage to acoustics in all ordinary cases; but when thus located there should also be a sufficient number of vents at the junction of the walls and the ceiling to allow the free escape of all heated air generated by the wall lights, otherwise it will distribute itself over the entire ceiling in pursuit of a path of escape, to the great injury of the acoustic properties of the room. When there is a large ceiling ventilator in the center of the room the heated air from the wall lights will instantly endeavor to escape through it by the shortest possible route. If the ventilator has a strong draught the heat from the lights will take nearly a straight path across the room space from the gas light to the large center ventilator. When the ventilator has only a weak draught the heat currents from the wall lights will assume a path on a curve equal to about one-fifth of a circle, the radius of which is equal to about one-half the width of the room, or the level distance from the wall light to a point directly underneath a ventilator in the center of the room.

If the wall lights are properly arranged they will, in many cases, assist the acoustic properties of a room by the heated air arising tight against the walls and forming a cushion of air, which, by its travel and its greater density of strata, assists quite materially in destroying reacting sound waves from the walls,

which are generally one of the principal factors in propagating Echoes, Jars, Crashes, etc.

In taking up the "Great Niagara" of acoustical disturbance—the stage—it is probable that its conditions, requirements, results and possibilities can be demonstrated and, perhaps, best understood by comparison with its twin *fac simile* in miniature—the open grate—as in their workings and results they are practically identical, theoretically. The grate, in this case, is assumed to be one in which natural gas is used, and with being supplied with a gas log the entire length of the opening and a row of small holes or openings the full length of the log, so that when the gas is turned on there will be a row of flames that corresponds in location to the ordinary footlights of the stage. These flames form a sheet current of heated air that covers the entire open space of the grate opening. If the chimney has a good draught, all the products of combustion make an easy escape up through the smoke-flue; but should the chimney have a poor draught and a window, open at the top, be located near the grate, then it is a common thing for the window to entice the floating carbon and gas away from the chimney-flue, to the great annoyance of our eyes and nasal organs and the injury of furniture, tapestry, curtains, etc. In a like manner, only in a thousand-fold greater ratio, are the footlights of the stage when used in conjunction with the modern stage (fire-place) opening—"The Proscenium Arch."

The heat current produced by the footlights ascends to a point a short distance below the proscenium arch and then hesitates in its choice of those two great evils in acoustics—that is, whether to pass out through the large ventilator in the ceiling over the gas chandelier in the center of the auditorium, or dodge under the proscenium arch and escape up through the fly gallery, over the stage scenery, into the attic over the auditorium.

The heat current can easily be seen to move the fly curtains back and forth. It can also be noticed by watching a perpendicular line on the scenery, which will appear to have a serpentine or snake-like movement. The line does not move, but is simply deflected out of its position or location by the interference of the light waves caused by the optical properties of the heat current. If a person stand at one end of the stage, at the end of a row of footlights, and try to converse with some

one at the opposite end, the heat currents over the lights will entirely nullify any semblance of articulation, leaving only sound without language to be transmitted. If the lights should have a screen on both sides to keep the sound waves from spreading out and from traveling along the sides of the heat current, then the current will kill all sound waves and no sound will be heard at the opposite end.

The currents produced by the heat generated from the stage footlights are universally known to all rostrum or stage habitues in various ways. For example, the heated air in its upward draught or path causes a partial vacuum at the rear of the stage which, by natural laws, must be filled; thus, cold air rushes in to fill the vacancy, coming from the cellar, anteroom or any source of supply at hand, but never from the auditorium, as the heated air from the stage or rostrum footlights completely blockades that avenue of supply. The vacuum thus formed is the cause of the stage always being cold, or at least chilly —generally from two to ten degrees colder than the auditorium will be found under the same conditions. The "stage whisper" is allowable simply because the heat current is so strong and hard to penetrate with consonant sounds that a prompter can speak loud enough to be heard 50 feet or more, if the vowel sounds are a little subdued in their timbre or harshness, without danger of being heard by the audience. A person speaking in the center of the stage cannot be heard as plainly as one speaking at the ends of the footlights and outside the proscenium arch. It will be noticed that any person who has an announcement of anything of special importance to make from the stage generally makes it from the end of the footlights; or, if speaking from the center of the stage, he will advance to the front as far as possible, his appearance indicating that he is trying to penetrate some imaginary or invisible curtain or veil between himself and the audience. He leans forward, as a person naturally would in peeping through the lace curtains when wishing to see and yet be unobserved. The natural inference is that the speaker is trying to penetrate the heated air current of the footlights as far as possible so that the audience may be reasonably sure of hearing the announcement correctly. With the drop curtain down and, as a consequence, the shutting off of the escape of the heat current up through the fly gallery into the

attic and over the auditorium, the speaker can be heard more distinctly, partly from the re-enforcement of the voice by the curtain, but more especially because of the reduced amount of the heated air current from the footlights, it being cut off at the crown of the proscenium arch. The effect of the curtain on the heat current, in cutting off its escape through the proscenium arch, is similar to that of one generated over an ordinary lamp. Remove the lamp chimney, or lower the drop curtain, and you will almost instantly notice the difference in the quantity of heat supplied.

It is plain, beyond a doubt, that gas, or lights that are the result of combustion, are entirely unfit for the lighting of audience rooms, and should never be used for that purpose. If good acoustic properties are required, or even desired, then the use of gas for footlights has not one single argument in its favor; but, on the contrary, a solid array of objections to it. To my mind, from an acoustic standpoint, it presents an example of a very limited knowledge of the philosophy of sound on the part of the person who is responsible for its use for lighting purposes. If footlights are used, supply the required illumination by electricity or any other source that produces light without heat.

When the conditions are such that the use of gas for illuminating purposes is necessary for both the auditorium and the stage, then it is best to remove the chandelier from the center of the room and close up the large ventilator. Scatter the lights over the rear half of the ceiling, using only one burner in a place. Set small ventilators in the ceiling, not over one foot square and not more than eight feet apart. Vents 6 x 6 inches, about six feet apart, will give the best results. The vents should open directly into the attic, and not into a ventilating shaft, as it is desirable that they cause the least possible air disturbance and make no draughts, currents, etc.

In lighting the stage, the best results are obtained by constructing the rigging loft, or the open space above the scenery over the stage floor, as tight as possible, so as to prevent currents from the footlights escaping up through the roof or over into the attic or other parts of the building.

There should never in any case, or for any pretense whatever, be an opening between the rigging loft and the attic over the auditorium, even if good acoustics were not considered at all. It

is very foolish from a fire insurance standpoint, as the stage and its appurtenances are, from the nature of their construction, of a very combustible character.

The stage should be ventilated by a series of small openings near the floor, set in the rear wall opposite the footlights. They should be as near together as convenient, and be all connected with a vent shaft that has a strong draught. For example, set a tube along the floor line against the rear wall; construct the tube so as to be about four inches at each end and sixteen inches in the center; connect it in the center with a hot-air ventilating shaft that has a strong draft, and cut a row of holes in the tube about two inches in diameter and two inches apart its entire length. The object of the tube is to draw the heated air generated by the footlights right across the stage and just above the floor. This will destroy the cold air vacuum now so common on all stages, and also, by its enticing power, steal away a great portion of the ascending air current, thus greatly improving the propagation, utterance and transmission of either language or musical sounds from the rostrum or stage to the audience.

CHAPTER VIII.

IN THE preceding pages it has been the aim to treat or consider Acoustics from an obstructive point of view, or, in other words, the results and effects of obstructions to sound waves as they travel, and how these obstructions tend to deaden, nullify or kill articulation by their cutting off or interference with sound waves.

In the following pages the subject of Acoustics will be treated from the opposite side of the question under consideration, viz.: Acoustics that are the result of assistance either for good or defective hearing through the re-enforcement of the primary sound waves in their travel by, and in conjunction with, crashes, jars, echoes or reverberations (which constitute the major component parts of resonance), which, in their propagation, embody the flexibility of sound waves or the property air possesses of continuing in vibration after propagation ceases to exist, or the effect of a vibration of a sound wave returning from a surface or concavity and re-enforcing the primary vibratory motion of the air. Resonance may be properly divided into sympathetic, simple, primary, nodal, compound and complex. (For detailed description of Resonance, see pages 17–19.)

Architectural Acoustics by Resonance are directly the result of the form, shape, and material used in the construction of auditoriums, which cause the sound waves to rebound in proportion to the density of the materials that have been used in the construction.

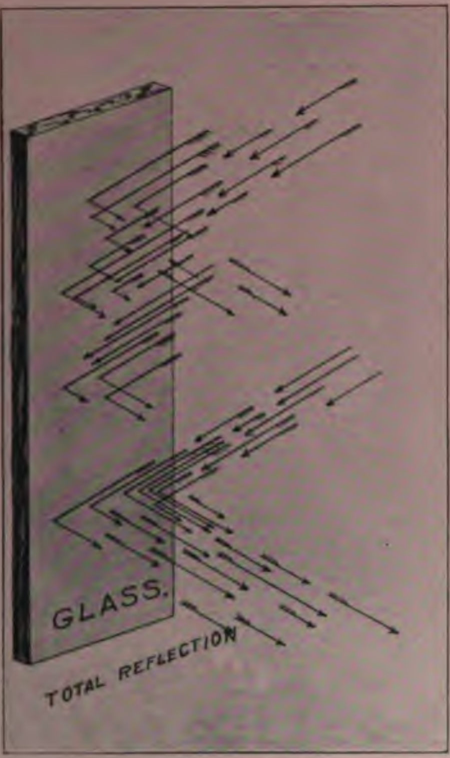
How startlingly distinct is the sound of the joiner's hammer in a newly plastered house! Even the stamp of the foot on the floor sets numerous echoes and reverberations into active competition for supremacy. The artisan's merry whistle sounds like the carolling of the birds in the spring-time as it rebounds from the hard plaster walls and bare floors. If the floor be of slate,

tile or marble, or even a polished floor of hard wood, the echoes, etc., are greatly augmented or re-enforced. So also do the walls increase the volume of sound in a corresponding degree or ratio if the walls are plastered and finished with a putty coat and smooth, trowel surface. If the walls are covered with any, or at least many, of the recently patented plasters now on the market, such as "King's Windsor Cement," "Eureka," "Adamant," and plasters of like nature in respect to their density, then the echoes, etc., are nearly double in volume and continuity to that propagated by the common mortar. Then, again, if the walls be plastered with the above-mentioned mortars directly on any hard surface, such as a solid brick or stone wall, or even plastered on stiffened wire lath, the echoes will be quadrupled to such a degree that should a blow be struck with a hammer a hundred echoes, etc., hasten to answer. The word "ha!" calls forth a jumbled, conglomerate chorus of "ha, ha, ha's" from all remote parts, not merely of the one room from which the sound is uttered, but also from all surrounding and connected rooms, but in a slightly reduced volume from adjacent rooms. Marble wainscoting, wall mirrors, etc., act as sound reflectors, and, unless properly set, will greatly injure the hearing properties of a room.

Echoes, crashes, jars, etc., are caused by the infinite flexibility of the air, which is practically incomprehensible to the ordinary mind. The vocal organs of the ordinary house cricket are less than one-eighth of an inch in length, smaller in fact than this letter, "o"—yet the air is, by its infinite susceptibility to agitation or vibration, capable of being set into violent vibration by the cricket's vocal organs. A volume of air the size of a City Hall can be easily set in motion by the chirp of the cricket. Thus, it seems that the controlling of sound waves in the law of reaction from wall surfaces is a very important factor in the production of proper acoustics.

The painter drops a hunk of putty on the floor; it strikes with a dull thud; there is no rebound, as the putty is devoid of that property known to science as flexibility.

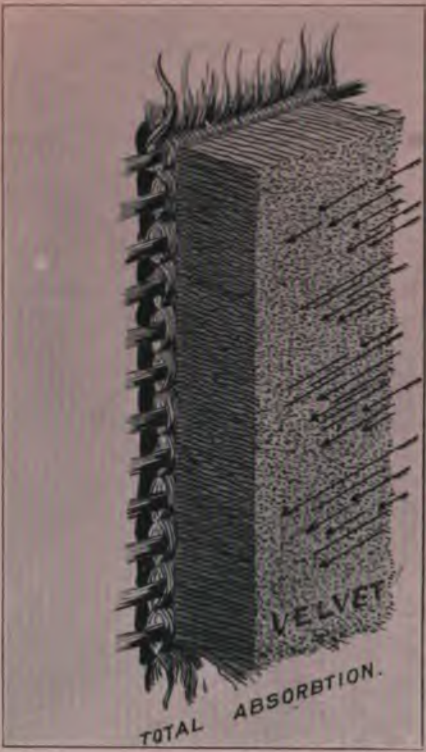
Reaction, or rebounding, is the result of two or more flexible bodies being forced into contact. To prevent reaction, both bodies in contact must possess the power of flexibility, the extent of which determines the force of the reaction. The



greater the difference in the density of the bodies in contact, the better or more active will be the results. Bodies of like density and composition have a tendency to nullify reaction, as their material composition decreases in density.

A stone marble that is dropped from a height of about six feet will rebound about two feet, and a wooden ball dropped on a plank will rebound about one foot. A ball of yarn dropped, under like conditions, upon a heavy, woolen carpet will rebound about six inches. The ball of wool may be thrown with great force on the carpet, yet there will be no reaction, as flexibility is absent both in carpet and ball of wool. The greatest reaction occurs when the two bodies in contact have a wide difference in their density. A ball of India-rubber, thrown against a marble block, is the best example known to the vision; while the air, in contact with a polished plate of glass, is the best known example to the hearing faculty of man.

If we step into a newly-finished room, after draperies have been hung and carpets laid, we immediately discover the entire absence of all echoes and reverberations. The draperies and carpets, being devoid of all flexibility, have absorbed or killed the resonance of the carpenter's hammer and the artisan's merry warbling whistle, leaving only sweet silence to accompany language and music, instead of a jargon of aggravating echoes and reverberations after every word or sound uttered by a speaker or



musician. The singing of a canary bird has a far less piercing sound in a room that is furnished with thick, heavy carpets and draperies and upholstered furniture, as the cloths absorb or kill the sound.

Air possesses the greatest amount of flexibility of all known things; while silk, cotton and wool are the greatest absorbent of sound waves, as they are practically devoid of all flexibility or resonant properties. Common sawdust, sifted on the floor of an empty room, one-half inch thick, will greatly improve the hearing properties of any room that abounds in echoes and reverberations.

Where a room has been constructed on the wrong principle for good acoustics and abounds in echoes, etc., the easiest method to remedy this defect is to cover the reacting walls with some soft, dead or non-reflecting material, corresponding in finish to velvet or carpets. Only the walls that return the sound waves need be so treated.

WIRES ACROSS CEILINGS.

There prevails a theory among nearly all public speakers and singers, and also with many of our most prominent architects, that the stringing of wires across the top of a room stops echoes and reverberations. This idea seems to be simply founded on an abstruse, vague theory, without any demonstration of fact, and is devoid of science and, practically, of common sense.

How can the stringing of wires across the ceiling of a room prevent echoes and reverberations when sound waves travel back and forth from the stage or rostrum to all parts of the room in one vast body, like the flow of a mighty river? Would any person of average intelligence endeavor to stop the current of a river, or even a brook, by driving a row of one-inch fish-poles across it, like a line of fence-posts? Set the poles twenty feet apart and note the effect they have on the current. Each and every pole disturbs the water directly in front of it to the extent of its full diameter, and on the sides to about one-half its diameter; or, in other words, the pole nullifies a strip of the current two inches wide and allows 19 feet 10 inches of water to rush by undisturbed. That is the exact ratio of improvement that a No. 20 wire, stretched one foot apart across the ceiling, will give to the acoustics of a room. The wire stops only the one hundred and twentieth part of the sound wave, leaving the balance to travel on to form echoes and reverberations.

Wire cloth, with the meshes not over one-fourth of an inch apart, will in nearly all cases stop reverberations; but single wires are worse than useless, for in cases where they are strained taut they act by resonance or in sympathy with any sound that is uttered, the same as a piano will respond (about one-fourth as loud) to the pitch of any note struck in close proximity to it.

Then, again, any string or wire, if strained taut, will respond to from four to twelve different pitches corresponding to its fundamental pitch and its overtones or harmonics, as *Do*, *Mi*, *Sol*, *Do* in music. Suppose the ceiling of an auditorium has stretched underneath it about 50 wires, each wire being endowed with the property of sonority or of being capable to respond to any sound that corresponds to it, then, as each wire has at least four different pitches to which it will respond, there are 200 different sounds to which the 50 wires are ever ready to answer. The average soprano voice does not exceed two full octaves, or, at most, 24 to 28 different pitches, chromatic included. The 50 wires will respond on an average about six times to every one of the different notes that the human voice can produce; which indicates to my mind very plainly that the wire theory is but another demonstration of the very limited knowledge and understanding of Acoustics.

If wires *are* to be used, stretch them on side walls and over all circular concavities. Keep them off the ceiling. The more used and the closer together the better. Never stretch the wires single, but weave them together, basket fashion; then there is no chance for them to assist reverberation.

In order to effect any noticeable improvement, the wires must be at least as close together as two inches. Use only soft copper or annealed iron wire, as steel wire will respond to a sound much more quickly and with greater volume than wire of a softer or more pliable nature.

Another theory that has been advocated by some persons is the use of demijohns, or large bottles, set in such a manner that their open mouths will project through and be flush with the inside of the walls and ceilings of rooms that possess reverberations, etc. In our opinion, a more senseless theory is hardly possible of conception, for the reason that a bottle, or any article that is hollow and encloses air, is a resonance chamber or pocket which, by the laws of resonance, tend to increase or re-enforce sound waves, be it tone, echoes, reverberations or any other cause of air disturbance, and does not in any way, condition or relation have any tendency to modify or nullify sounds. Resonance pockets may be used under certain conditions to increase sound, but never to stop echoes and reverberations. Such a result could not exist.

RE-ENFORCEMENT OF SOUND.

In an auditorium that is too large for the voice to fill without great exertion and exhaustion on the part of the singer or orator, the voice can be re-enforced to a degree that will make vocal rendering easy of execution, and agreeable to hear, by the use of a set of resonance tubes or pockets, located near the pulpit, rostrum or stage, as the case may be. For example, take a tube say two feet long and two inches in diameter (which is the size and diameter required to produce the pitch of middle C on the piano), either round or square, of wood or metal, and close or stop up one end tight; set about ten feet away from the speaker or singer, with open end or mouth in line or range with your

vocal organs. Then utter a sound at a low pitch, about G natural below middle C on the piano, and prolong the sound in a true, even volume, gradually raising the pitch up to the octave G. As you do this, carefully note the difference of tone and volume, and you will discern that the instant you change above the pitch of G the tone dimishes in volume about 20 per cent., and continues diminished until your voice in its upward glide reaches the pitch of C, when the volume of tone instantly assumes its full power, with at least 50 per cent. contributed to it by the speaking sympathetic resonance of the tube. When the voice leaves the pitch of C and continues its upward glide, it will again diminish in volume until it reaches the pitch of E, where it will be re-enforced about 30 per cent.

The reason that the voice is more strongly re-enforced at the pitch of C than at those of E and G is that a tube two feet long has, in its own speaking properties, the same number of air vibrations as the voice has when uttering a sound at that pitch. Hence, the tube and the voice, in propagating sound, act in perfect unison. The diminished volume of sound observed at the pitch of E or C is due to the fact that the air vibrations of the voice and the tube have a different number of sound waves to the second of time at those pitches; yet the tube responds and re-enforces the voice in propagation to the common divisor of their air vibrations. For example: Assume the voice and also the tube to each have 24 vibrations of air to the second of time; the pitch of G to have 20, and E to have 26. In such a case the relative increase in the volume of sound contributed by the tube at the pitches of E and C is in direct proportion to 24, or the greatest common divisor of the number of vibrations of E and G to those of C, which is the pitch of the tube. Therefore, if the tube re-enforces the voice at C by 24, then it will re-enforce the voice by 13 at E and 10 at the pitch of G.

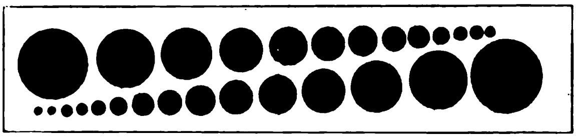
RESONANCE TUBES.

From the above it can readily be determined that if one tube will re-enforce the voice at one fundamental and two harmonic tones, then, if there are as many tubes in readiness for action as there are musical pitches, the whole musical gamut can be

re-enforced and strengthened to the same extent as the one tube of C assists that wave sound of the voice.

In sympathetic tube resonance for sound re-enforcement, the best results are obtained by locating the tubes as near the speaker or singer as possible. Where the conditions of the building will admit, it is best to cluster the tubes in a bundle, or any form that is compact. If so arranged, one set of tubes will be sufficient to meet all requirements. When possible, set the tubes directly over the voice of the speaker—in the ceiling, if convenient—but at a distance not to exceed twelve feet from the voice. The nearer the tubes the better will be the results. In the case of a stage with a large proscenium arch, the tubes may be set in the stage, about one inch above the floor, just inside of the footlights; but in no case outside or on the auditorium side of the lights. The tubes must be placed vertically, and should have caps on the lower ends so that anything that may drop into them from the stage can be removed.

If the conditions are such that the tubes cannot be clustered and have to be set in a line, then it is best to use two sets of tubes, with the ranks diminishing in opposite directions. Use one set with open and the other with stopped ends, as the stopped tubes are pitched one octave lower than those open, and the whole range of musical pitches can thus be thoroughly treated. The tubes also assist the singer or instrument to keep exactly on the correct pitch, because the voice responds much more readily and maintains a larger volume of tone, with the same exertion, when it is gauged on the same pitch as the tubes. The cornet will blow freer and the violin will speak clearer when correctly pitched. There will be no bad results if the voice or the instruments are not exactly on the same pitch as that of the resonance tubes. The effect will be the same as though no tubes were about the building. The voice and instrument would simply lose the benefit of the resonance of the tubes by being off their pitch.



RESONANCE TUBES INJURIOUS.

Resonance tubes that are used for increasing the volume of tone produced by the voice or instrument will also increase the reverberations, echoes, crashes, etc., in the same proportion as they increase the voice or instrument. Hence, it will only make a bad matter worse to use tubes in a room that already possesses defective hearing properties, or bad accoustics, due to faulty construction, either in its shape or from the materials used. Resonance tubes can only be used to an advantage to increase the volume of tone in large auditoriums in which no reverberations, echoes, jars, crashes, etc., exist even in a slight degree, and should be used for no other purpose whatever under any circumstances.

TABLE OF SIZES OF RESONANCE TUBES.

In preparing the scale of dimensions of resonance tubes the greatest possible care has been taken to give all the sizes with mathematical accuracy in the proportioning of the chromatics, with due reference to the augmented interval between G sharp and A flat in the major or diatonic scale in music—the overplus of pitch between G sharp and A flat being evenly distributed over the entire set of different keys in music.

The table on the two pages that follow this give the exact length and inside diameter of a complete set of tubes required for all pitches of the chromatic scale, covering a range of six complete octaves. The sizes given are the same as used in the standard diapason pipe of the latest improved pipe organ.

WOODEN, OPEN DIAPASON PIPES, RECTANGULAR SECTION.

	Name.	Diameter. Ins.		Diameter. Ins.	Length. Ft.	Length. Ins.
Zero.	**CCCC**	**6.00**	x	**7.00**	**16**	**0.56**
	C♯	5.75	x	6.75	15	2.19
	D	5.56	x	6.50	14	4.31
	D♯	5.37	x	6.25	13	6.94
	E	5.18	x	6.00	12	10.06
	F	5.00	x	5.75	12	1.62
	F♯	4.81	x	5.50	11	5.62
	G	4.62	x	5.25	10	10.06
	G♯	4.44	x	5.06	10	2.87
	A	4.25	x	4.87	9	8.06
	A♯	4.06	x	4.69	9	1.62
	B	3.87	x	4.50	8	7.50
O. Low.	**CCC**	**3.69**	x	**4.31**	**8**	**1.69**
	C♯	3.50	x	4.12	7	8.19
	D	3.31	x	3.94	7	2.94
	D♯	3.19	x	3.75	6	9.94
	E	3.00	x	3.56	6	5.19
	F	2.87	x	3.37	6	0.69
	F♯	2.75	x	3.25	5	8.44
	G	2.62	x	3.12	5	4.44
	G♯	2.50	x	3.00	5	0.62
	A	2.37	x	2.87	4	9.00
	A♯	2.25	x	2.75	4	5.56
	B	2.12	x	2.62	4	2.31
Low.	**CC**	**2.06**	x	**2.56**	**3**	**11.25**
	C♯	2.00	x	2.44	3	8.69
	D	1.94	x	2.31	3	5.87
	D♯	1.81	x	2.19	3	3.56
	E	1.75	x	2.09	3	1.25
	F	1.62	x	2.00	2	10.94
	F♯	1.56	x	1.87	2	8.75
	G	1.50	x	1.81	2	6.81
	G♯	1.44	x	1.71	2	5.06
	A	1.34	x	1.62	2	3.37
	A♯	1.28	x	1.56	2	1.75
	B	1.21	x	1.46	2	0.12

Name.		Diameter. Ins.		Diameter. Ins.	Length. Ft.	Length. Ins.
Middle.	C	**1.15**	x	**1.40**	**1**	**10.50**
	C♯	1.09	x	1.31	1	9.06
	D	1.06	x	1.28	1	7.81
	D♯	1.00	x	1.21	1	6.56
	E	.93	x	1.15	1	5.50
	F	.90	x	1.12	1	4.50
	F♯	.87	x	1.06	1	3.56
	G	.84	x	1.03	1	2.62
	G♯	.78	x	1.00	1	1.87
	A	.75	x	.96	1	1.06
	A♯	.71	x	.90	1	0.31
	B	.68	x	.87		11.56
Octave.	CC	**.67**	x	**.86**		**10.87**
	C♯	.65	x	.83		10.19
	D	.64	x	.80		9.50
	D♯	.61	x	.76		8.94
	E	.58	x	.75		8.37
	F	.56	x	.72		7.90
	F♯	.54	x	.68		7.50
	G	.53	x	.67		7.03
	G♯	.51	x	.66		6.56
	A	.50	x	.64		6.12
	A♯	.48	x	.62		5.71
	B	.46	x	.61		5.37
High.	CCC	**.45**	x	**.59**		**5.03**
	C♯	.43	x	.58		4.71
	D	.42	x	.56		4.43
	D♯	.40	x	.54		4.18
	E	.38	x	.53		3.93
	F	.37	x	.51		3.68
	F♯	.35	x	.50		3.46
	G	.34	x	.48		3.25
	G♯	.32	x	.46		3.03
	A	.30	x	.45		2 81
	A♯	.29	x	.43		2.62
	B	.27	x	.42		2.43
O. High.	CCCC	**.25**	x	**.39**		**2.28**

CHAPTER IX.

SOUNDING BOARDS—or, what should more properly be called, Sound Reflectors—that are used to transmit vocal or musical sounds, are of three kinds, viz.: Plano or flat surface, concave or receding surface, and convex or approaching surface, which, by their material composition and mould of surface, reflect sound waves either in parallel, converging or radiating lines, the timbre of the reflected sound being of an even, graduated or irregular homogeneous strata, having a gradually dimishing density from reflector to end of travel.

SOUND BOARDS INJURIOUS.

Sound Reflectors act in the same manner and have the same result on vocal sounds as resonance tubes when used for increasing and transporting a greater volume of tone to the voice or instrument. They will also augment the reverberations in exactly the same ratio as they increase the volume of the fundamental or primary sound. Hence, it would be worse than folly, and only make a bad matter considerably worse, to employ sound reflectors in a room already having defective acoustical properties.

Sound Reflectors should be used only for transmitting sound waves, and for no other purpose whatever. They are intended to be used only in rooms that are too large for the voice to fill, or in special cases they may be used in rooms that, from their proximity to railroads, street-car lines or any large noise-propagating factories, require artificial assistance; but even in such cases the room must be devoid of all reverberations.

MATERIAL FOR CONSTRUCTION.

The transmitting properties of a sound reflector depend principally on two things; first, the material used in its surface construction, and second the mould or form of its reflecting surface.

Air, when propagated into sound waves or oscillating vibrations, is in its action the most perfect example of the flexibility of matter known to the human mind. The sound waves, when in contact with matter or any kind of surface, are so infinitesimally delicate in their contact, so marvellously gentle in their touch and rebound so faintly as to be beyond the limit of human comprehension, and only instruments of microscopic accuracy have been able to determine the power of their contact and the elasticity of their rebound or reflection.

Then, again, the difference in the density of the condensations and rarefactions of sound waves are of such a construction and character as to defy all mechanical apparatus to scale, even approximately, any difference in their gravitate density. The human ear, in its normal state of perfect health, with the highest degree of musical and scientific cultivation and development possible, is yet unable to accomplish more than to register in the mind the pitch and volume of sound.

The contact of sound waves, as they break in a ceaseless torrent on the tympanum of the ear, is too infinitely delicate in the touch to reach or come within the limited boundary of human conception. It would seem to the author as easy to calculate the extra weight that the aroma of a rose would add to the atmosphere in a room as to accurately determine the relation in density between sound waves and their accompanying rarefactions.

By the laws of flexibility we find that two bodies in contact give or produce the greatest reaction in the same ratio as the difference in their density increases. Therefore, in constructing a sound reflector, the greater the density the reflecting surface presents the more complete is the reflection obtained.

From microscopic examination of matter by many scientists it has been definitely ascertained that all matter is composed of minute particles or irregular chunks of substances composed of one ingredient, these particles being termed atoms or molecules.

By the shapes of their undivided atoms and their arrangement into clusters or groups they constitute matter, be it wood, stone or metal.

If the atoms are in a loose pile, then the substance formed is light and porous in nature, like soft wood, leather, cork, etc.

If the atoms are in a compact mass, the substance formed is similar to sandstone, brick, plaster of Paris.

When the atoms are of geometric form, as cube, rectangle, triangle or polygon, they will fit tight together in regular order, not unlike, in general appearance, to a brick wall, mosaic floor or cabinet inlaid work. The tighter the atoms fit at their union with their neighbors, the closer or greater will be their density. Geometric clustered atoms form all hard or fine, close-grained material, such as metals, marbles, hydraulic cements, etc.

By the laws of reflection, the sound waves will rebound from all the flat, smooth surfaces, by the angle of their reflection being equal to the angle of their incidence, thus reflecting the volume of sound in proportion to the density of the surface of the reflector.

If it were possible to construct a surface that would be microscopically smooth and true, with no holes or interstices to absorb the sound waves, then the whole volume would be reflected. From the practical standpoint of building construction, reflectors should be of sheet metal, plate glass or hard, smooth plaster to be practically correct, or as near so as to reach the limit of the conception of the human ear if unaided by scientific instruments.

STATIONARY REFLECTORS.

Where it is necessary to use a sound board, and the conditions will admit, it is far better to make it a permanent fixture of the auditorium by building it into the walls back of the stage or auditorium.

In all cases a reflector with a surface of mortar is the best, both in its results and also as to cost.

The way to construct this kind of sound reflector is as follows: Erect the skeleton frame of ribs of timber not less than 2 x 4 inches in cross sections, set twelve inches on centers and edge-

wise to the reflecting surface. Overlay the entire reflecting surface, and also the outside or back of the reflector, with kiln-dried, narrow, matched lumber one inch thick.

Overlay the inside with two layers of matched lumber, laid diagonally across the ribs and also at right angles to each other. Thoroughly nail the layers to the ribs, and also nail every four inches both ways with 1½-inch wrought iron nails. Clinch the nails down, and draw the layers of the covering tight together. Then fill in the open spaces between the sheathings and ribs with the best quality of whipped asbestos or mineral wool. Use wool that is of open fibre, similar to the curled hair that is used for furniture upholstering. The wool should be packed tight into all the corners, etc.

Strip the entire reflecting surface on the top of the diagonal sheathing with ribs 1 x 1½ inches, and set twelve inches on the centers. These ribs should be set on the edge and directly over the ribs of the frame. Fasten the ribs in place with 2½-inch screws, No. 8 gauge, with the screws not more than one foot apart. Cover reflecting surface with stiffened, woven-wire metal lath. Overlay the lath with two coats of plaster—one brown and one putty. Lay a heavy coat of brown mortar under heavy pressure so as to give extra good clinch on lath. Leave the brown coat with rough, scratch sand finish until it is perfectly dry and hard, and then lay second coat of putty, composed of equal parts of clean, white glass sand, marble dust, plaster of Paris and fresh-burned quick lime—the lime to be slacked at least ten days before using. Lay this coat at least three-eighths of an inch thick, and finish as smooth and true as possible. The smoother and truer the finish the better the reflector will re-enforce the voice. As soon as the last coat of plaster is finished, cover the sounding board with a heavy canvas, thoroughly drenched with water, for the purpose of retarding the seasoning and drying out of the plaster, as mortar is far denser and tougher if allowed to dry slowly.

At the time this putty coat is being laid, prepare a good, strong, brown mortar for puddling, the same as used for the first coat of reflecting surface, the mortar to be liquid enough to settle to a level if heaped on the floor in a pile.

Turn this semi-liquid mortar into the spaces between the wire or metal lath and the wood sheathing on the reflector side

of the sound board. Tamp down around the plaster clinches until it unites with the back of the brown coat of plaster and forms one solid, compact mass with the plaster of the reflector. The whole mass should not be more than 2½ inches thick. When the mass of plaster has become thoroughly dry and seasoned, paint over the entire surface of the reflector with two coats of gum shellac cut in alcohol, and three coats of best lead and oil. After the lead is dry, polish the surface down true and smooth with pumice-stone and water, and finish with two coats of A No. 1 Demar varnish. Rub the first coat of varnish to a true surface, leaving no brush ribs or waves to show, and leave the second and last coat with the finest piano finish possible. The whiter the color and the finer the polish, the greater will be the volume of sound or voice reflected.

MOVABLE REFLECTORS.

Where the construction of the building is such that a fixed sound reflector would be impracticable and an obstruction to the entertainment or performance, and only a movable one can be used, such a reflector is best constructed as follows:

Lay the sill of one bent piece of hard wood about 1½ inches thick by four inches wide, bent flatways and set up on the edge. Construct frame of ribs 1 x 1½ inches, bent edgewise and mortised into the sill, and also mortised into the key-block at the top. Set the ribs twelve inches apart on the sill, and bring them together at the key-block. Cover the reflecting surface with extra heavy Russia stove-pipe iron or heavy zinc plate, the thicker the better. Cover the outside or back of sound board with heavy roofing tin, lock-seamed and soldered. Cut the Russia iron covering plates of one long, lancet-shaped piece of metal that will reach from the center of one rafter or rib to the center of the next rib. Make no cross splices—the rib sheets must run the entire height of the sound board without a joint. Lap the metal about one-half inch on each rib, and nail every two inches along the lapping edge with wire nails that have small, flat heads. Drive the heads down flush, being careful to

make no dents, wrinkles, etc., as they detract from the reflecting properties of the sound board.

All metals should have a clean, smooth surface, free from all seams, buckles or blisters.

Lay strips of heavy brown wrapping paper, about one inch wide, between the joints to act as a cushion and prevent the metal from tinkling or clatteriug when receiving very heavy vocal or instrumental sounds to transmit.

Fill in the spaces between the ribs and the heavy metal sheathing with asbestos fibre mortar—the same material that is used to cover steam pipes. Tamp the filling in tight in all corners, and leave the entire mass solid and compact.

Finish the reflecting surface with one coat of oil, one coat of shellac, three coats of Cornell's best white lead, and two coats of best Demar varnish. After the lead is quite dry, polish down true and smooth with pumice-stone. Rub the first coat of varnish to a true surface, and leave the last coat with the finest piano finish possible.

SOUND REFLECTORS.

Sound Reflectors are of two kinds, viz.: Constructed sound boards, as above described, as one kind ; their purpose being for the transmission of sound from certain locations, or points of propagation and issue, to certain other locations or areas, as over the seating of an audience room.

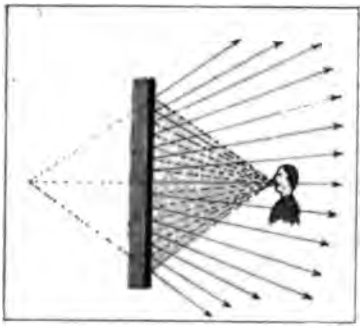
The other kind of reflectors constitute and comprise all surfaces of all kinds that enclose air space, including all walls, floors and ceilings of rooms, alcoves, pockets, etc., of every kind, form or nature.

By the laws of philosophy we find that air, both in quietude and also under disturbance, is under the same inexorable law that governs heat, light and all other matter. Hence, in Acoustics, air in action, transmission and reflection bows in obedience to the law embodying the principles of angles and nodes, *i. e.:* "The angle of incidence is always equal to the angle of reflection."

Sound boards, floors, walls or ceilings of all auditoriums will always act as Sound Reflectors, with results in exact proportion to the form and density of their reflecting surfaces, and can be properly divided into three different classes, viz. : Radiating, Paralleling and Condensing Reflectors, according to the method by which they reflect sound waves, and also by the results obtained. Their form is either plano, convex or concave, and they reflect the sound waves either on parallel, radiating or converging lines, with their timbre of an even, graduated or irregular homogeneous strata, having gradually dimishing density from the reflector to the end of travel in the realm of silence.

PLANO REFLECTORS.

A Plano Reflector is one that has a flat surface, such as a sheet of window glass, the ceiling of a room, or the surface of placid water. A Plano Reflector has but one property, that of radiating sound waves without changing their method of travel in timbre or their lines of radiation. It simply changes the direction of radiation from the point of propagation and issue to an imaginary point behind or back of the surface of the reflector. The reflected wave is the same, regardless of the location of the point of sound propagation and issue.



The density of a reflected wave is always graduated from the point of issue of sound to silence, in that sound decreases in volume and density as the square of the distance from the point of issue to silence increases.

The greater the density of the wall material used in the construction, and the smoother the surface, the greater will be the volume of sound transmitted to other locations in the auditorium, these transmitted sound waves being the main factor in propagating all kinds of sound disturbances, as illustrated on pages 34, 35 and 36.

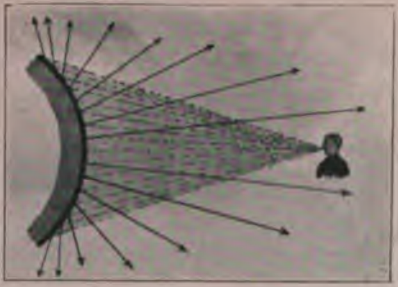
CONVEX REFLECTORS.

Convex Reflectors are of two kinds—one having a curved and the other a spherical surface, both of which approach the generating point. The curved surface is of two forms—the hyperbolical and the elliptical. A good example of the form of a hyperbolical reflector is to take a hen's egg, divide it transversely in the center of its length, and use the smaller end.

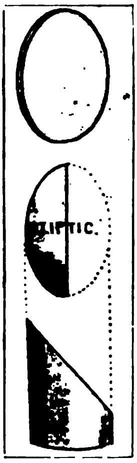
In geometry or mechanics, a hyperbola is generated or formed by cutting a slab off a cone having a circular base, the division being made by a vertical cut or square with the base of the cone, the edge of the slab being a perfect hyperbola.

A parabolic concave reflector, shown above the egg oval, is nearly the same form as the hyperbolic, and also possesses the same general properties of reflection. This form of reflector is in general use for locomotive headlights.

A Convex Reflector is one that has the reflecting surface approaching the point of sound propagation and issue. It is formed around a generating point that is located on the back or opposite side of the reflecting surface from the point of sound propagation and issue. All convex reflectors possess but the one property of reflecting sound waves in radiating lines and changing their lines of travel to correspond to an imaginary foci located at the rear of the reflector. This focal point is possessed of the property of a continuously changing location, as every reflected ray of sound changes its line of travel in a greatly augmented radiation from the center of the reflector in all directions towards the outer edge.



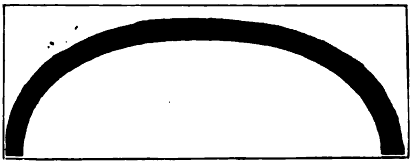
ELLIPTICAL REFLECTORS.



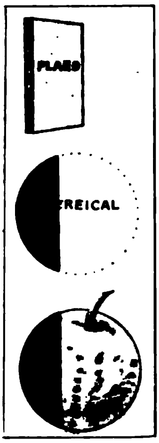
An Elliptical Reflector corresponds in form to the outline of a circular disc, as a silver dollar for example, when viewed in perspective or on an oblique angle to the point of vision. All outline forms of Elliptical Reflectors may be nicely demonstrated by slowly revolving a silver dollar, held by calipers, between the eye and a strong light.

In geometry or mechanics, an ellipse is generated or formed by the cutting of a cylinder on an angle between its transverse and longitudinal dimensions.

The form of the ellipse is determined by the angle of the cut across the cylinder, being a perfect circle at right angles with its axis and a square or rectangle parallel with the axis, gradually changing and lengthening its form at every angle from the circle until it approaches the rectangle.

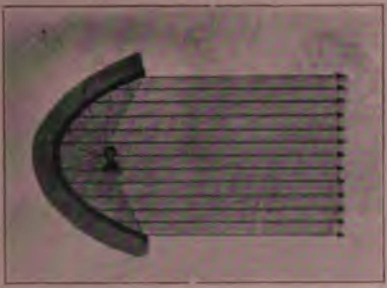


SPHERICAL REFLECTORS.

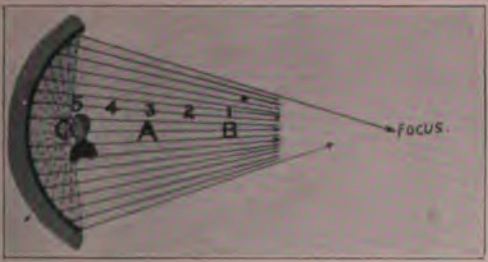


A Spherical Reflector is one that has every point of its surface an equal distance from its focus or generating point. An example is found by cutting a slice off an apple, orange or cocoanut and removing the pulp or inside. The inside of the shell corresponds to a concave spherical reflector, while the outside corresponds to the form of a convex reflector.

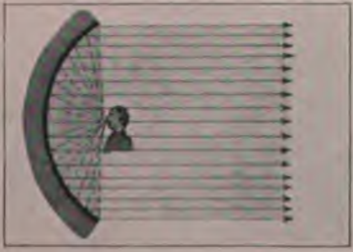
All Concave Reflectors possess the properties of reflecting sound waves in two distinct methods, viz. : In parrallel and in condensing lines, according to the location of the point of propagation and issue. For example : If the sound be issued at A, on the focus of the generating



curve, the sound wave will return on its own path to the point of issue. If the sound be issued at B, or twice the distance of A from the reflector, the reflected wave will focus at C, half way between A and the sound board. In like manner, all sound waves that are issued outside of the focus or generating point of concave reflectors will return and focus between the generating point and the reflector. The reflected wave will always focus the relative distance, but in a reverse order from the sound board to that which the point of sound issue bears to the generating center of the reflector, viz.: As the point of issue recedes from the sound board, the focal point of sound reflection approaches the sound board. If the point of issue located at B is gradually changed by a succession of points, as 1, 2, 3, etc., from B past A and to the point C, the reflected wave will change from a short focus at C to parallel lines.



If the point of issue be moved farther towards the sound board, or inside the point at C, then all reflected waves will be in radiating lines, corresponding to an imaginary traveling point or location of sound issue at the rear of the sound board or reflector.



How and what form of sound reflectors to use may be easily determined in a satisfactory manner, if the following principles are closely adhered to, viz.:

First—Sound must be issued from one point only in an auditorium. It would be a mechanical impossibility to construct a church, theater, hall or other auditorium with the pulpit, rostrum or stage at one end and the choir or other music at the other end, or that opposite to the speaker, and produce distinct oratory and articulate singing at the same time. One must be better than the other, or both will be faulty to an unbearable degree. Both speaking and singing, under such conditions, could not exist clear and distinct. It is a juxtaposition of propagation of sound waves, and a plain contradiction of philosophy.

Second—All sound reflectors, be they floors, walls or ceilings, must be of such a constructed form and material that they will possess but two properties: That of totally absorbing or nullifying all conflicting or misdirected sound waves, and also reflect all sound waves to the auditors only and in no case reflect to the walls or ceilings of a room, even to a remote degree.

How to find the proper kind of a reflector to meet any and all requirements is determined by the laws of reflection, *i. e.*: "The angle of reflection is always equal to the angle of incidence," and a node is always at right angles with the surface of the wall, ceiling, etc., at the point of contact with the sound wave. The nodal line is always midway between the angle of contact and the angle of reflection.

Having established the principles of the nodes, we find these problems confronting us:

First—Sound board behind speaker; all walls and ceilings dead. See page 85.

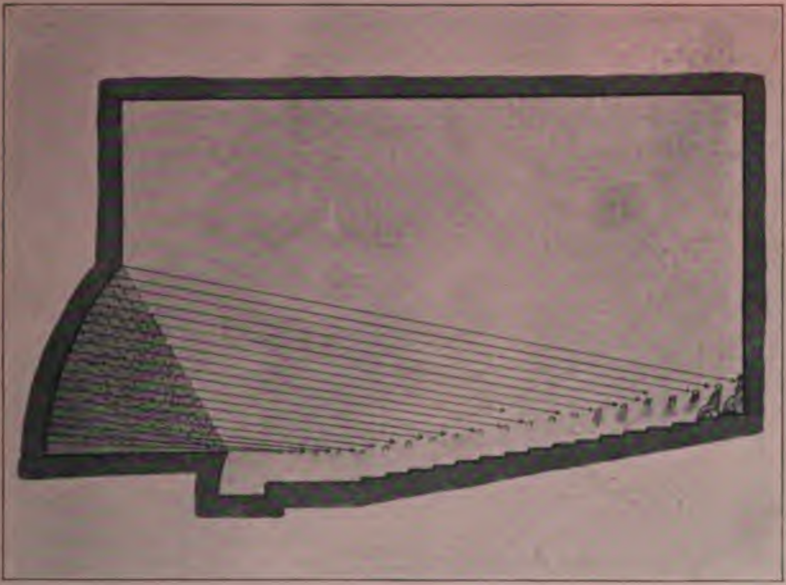
Second—Sound board behind speaker; rear wall a reflector; all other walls and ceilings dead. See page 87.

Third—Proscenium reflector; all walls and ceilings dead. See page 88.

Fourth—Ceiling reflector; the rear part of ceiling and all walls dead. See page 89.

Fifth—Gallery angle reflector; all walls and ceilings dead. See page 90.

SOUND BOARDS—ALL WALLS DEAD.



In the illustration above, we assume you wish to use a sound board behind a pulpit, in a room that is 60 feet wide by 100 feet long from front to rear. Divide the floor space into checks by the same method of division as used in the ordinary chess or checker board. Plat out the checks of sufficient size for one seat or person—size about 20 x 30 inches each, or a total of 1,440 sittings. Erect in the center of each seat check a small upright post about 2 feet 6 inches high, to corespond to the height of the ear of the auditor from the floor, and fasten to the top of the upright a thread or small line. Erect one upright post 5 feet from the pulpit or rostrum floor, on exact location to correspond in height to the voice of the orator or singer, if in a church; but, if in a theater, use the front of the stage floor, in the center, for the point of sound issue, it being about half way between the music of the orchestra and the speaker or singer on the stage.

The following method of sound board construction is used simply to clearly demonstrate the principle of reflection, and is

not intended to be used in general practice. The sound board construction that should be used is specified on pages 76–79.

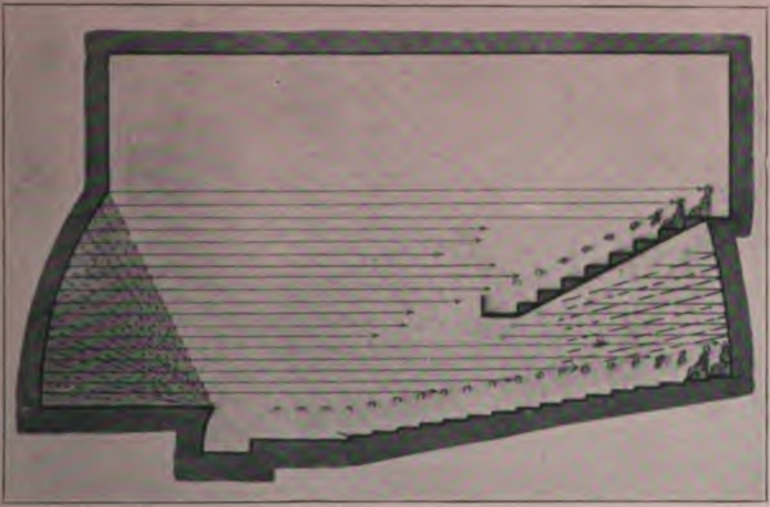
The sound board may be located any reasonable distance back of the singer or orator, but to be of greatest advantage it should not be nearer than 4 feet, nor farther away than 12 feet. The distance from the orator or singer establishes the size of the sound board as follows: String one line from the top of each upright at each corner seat in the room to the upright at the pulpit or stage front, as the case may be. Establish the location that the sound reflector is to occupy; then measure a distance from the pulpit upright out on the four lines towards the seats equal to the distance from the upright to the location of the proposed sound board, and the distance between the lines at that point will be the exact size of the sound board required for any place, condition or requirement. Any area larger is useless and wasteful as it will reflect sound waves against the walls; while a reflector that is smaller will omit some of the auditors. All reflectors should cover the audience, and no more. Having determined the size of the sound board, proceed to check it off in the same manner of squares or checks as were laid out on the floor space, or a total of 1,440 checks. Number the checks on the floor and sound board to correspond with each other, from 1 up to 1,440.

At this point let us change sound to light, to demonstrate the reflecting principle, as it is much more generally understood, and the principles can be proven by any one beyond the shadow of a doubt.

Place a lighted lamp at the exact position to be occupied by the orator or singer. Fill every seat in the audience room with a spectator. Take a mirror the exact size of one of the checks of the sound board; then begin at check No. 1, for example, and set the mirror in the sound board and tilt it into such a position that it will reflect the flame of the lamp from the center of the mirror directly into the face and eyes of the person who occupies the seat on check No. 1; tilt mirror No. 2 and reflect the light in the face of auditor No. 2; reflect mirror 3 into face 3; mirror 4 into face 4; mirror 5 into face 5; and so set all mirrors until each and every spectator in the room can see the reflected light of the lamp in the mirror that corresponds to their individual seat.

Remove the lamp and substitute a speaker or a singer, and you will have the most perfect sound reflector that could be imagined. On examination it will be found that the center of each mirror is at right angles with the nodal line, or a line midway between contacting and reflecting waves of light or sound. Hence, any sound board constructed on this form will reflect and evenly distribute every sound wave over the entire audience, free from any and all imperfections in acoustics.

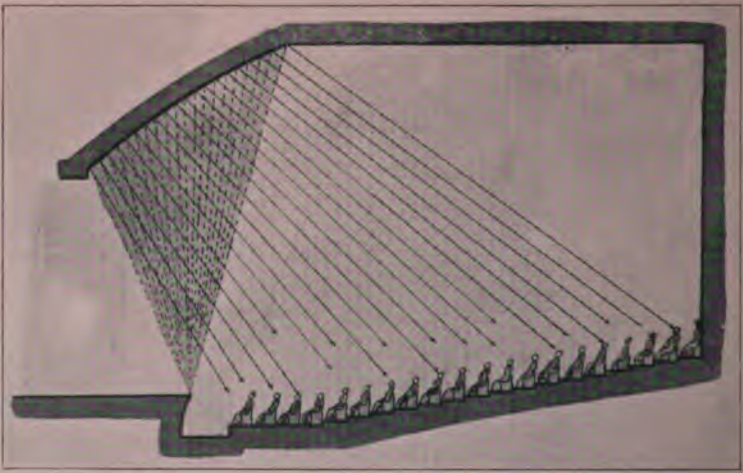
SOUND BOARDS BEHIND SPEAKER, WITH REAR WALLS A SOUND REFLECTOR.



The use of the rear walls as a reflector will produce good results in any room, but better results in a long, narrow room. The sound board should be of such a form that it will reflect the sound waves in parallel lines the full width of the auditorium and against the rear wall of the room, and must not overlap on the ceilings or sides of the room, or on the rear wall above the rear reflector. Construct the rear wall of the proper form to return the entire size of the sound wave back to the sound board

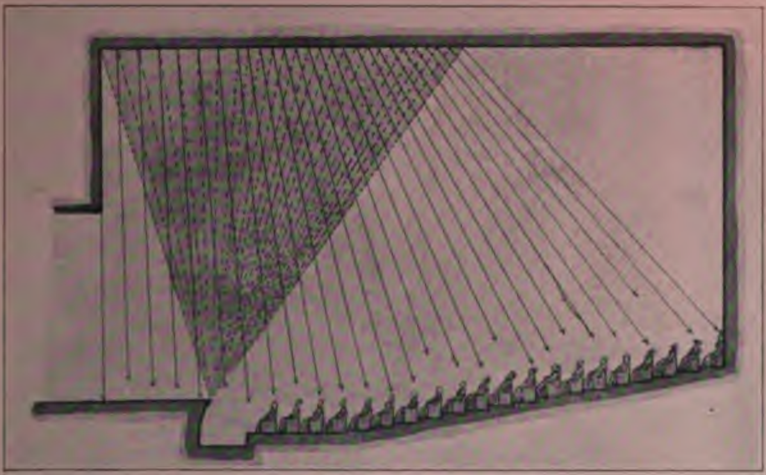
at rear of the speaker or singer. Where the rear wall under the gallery (as shown in cut) is to be used in conjunction with the pulpit or stage sound board, then the ceiling of the gallery should be constructed with a sound-deadening surface, as it would, if finished with a hard, smooth finish, reflect the sound wave, as it leaves the rear wall reflector, down on the audience and confine it back underneath the gallery, thus forming a perfect resonance pocket. Make all other walls and ceilings outside of the reflectors of dead, non-reflecting surface.

PROSCENIUM REFLECTORS.



When ceiling and wall over proscenium arch is to be used for a reflector, it should be constructed on the same principles as demonstrated in the example of the sound board of mirrors. The form of the reflector should be such that it will reflect the sound wave over the entire auditorium in a true, even, homogeneous strata, free from all disturbances. The reflected sound wave should cover the entire floor occupied by the seating space, and not overlap on the side walls, the stage, or the floor space outside of the line of seats.

CEILING REFLECTORS.

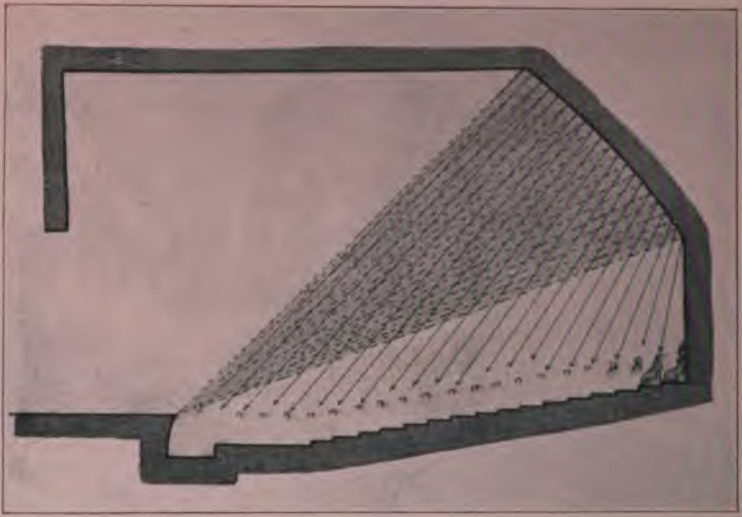


When it is necessary to use an old ceiling for a reflector, in the absence of a sound board, the size of the ceiling to be used may be determined as follows: Set up an upright to correspond to the height and location of the ear of a person occupying a seat in each corner of the room. Stretch a line from each corner upright to the speaker's or singer's location on the rostrum or stage. Measure one-half of the distance on the line from the speaker toward the uprights, and plumb up from these semi-distant points to the ceiling. The four vertical points marked on the ceiling give the exact corners, size and proportion of the ceiling reflector.

Such a ceiling reflector may be left flat, but it should have its surface finished smooth and hard, the same as specified for a pulpit sound board.

There is no case where any wall that is vertical can be used as a sound reflector, as all walls of this manner of construction are, by the form of their surface, plano reflectors, which are possessed of but one property—that of reflecting sound waves in radiating lines of travel, whereby they scatter the sound into all remote corners, progagating sound crashes and wedges. See page 80.

GALLERY REFLECTORS.



When it is necessary to construct a gallery reflector, it should be constructed on the same principles and by the same methods as used in the construction of the proscenium reflector. All walls and ceilings should be of dead, non-reflecting surface.

LEGISLATIVE HALLS.

Halls that are used for promiscuous speaking in different parts of a room cannot by any method be made acoustically correct, as every different location in the room used by an orator requires the rest of the room to be constructed to satisfy the requirements of the particular location in use at that certain time. Therefore, under such requirements, a room can be made only approximately correct by the following method of construction: Make all the floors and side walls dead to sound reflections, and construct the ceiling of the entire room as one immense sound board. The room in all such cases should be as nearly square as possible, without taking the height into

consideration. A room with a high ceiling will give far better results than one with a low one. A room that corresponds to a perfect cube will furnish the best results, although nearly any box-shaped room can be made sufficiently correct for all practical purposes. Domes in the center of rooms, angles and circular corners must not, under any consideration, be allowed. If they are, the room will be a total failure, so far as good acoustic properties are considered, as long as domes or circular corners remain.

In constructing the ceiling, place an upright on the exact or average center of the floor space to be occupied by the various speakers, the upright to correspond with the one used at the pulpit in generating sound board. With the upright established, generate the ceiling curve of such a form that it will reflect each and every sound wave vertically from the ceiling down to the floor, so that the entire space occupied by the various speakers may be completely covered. The reflected sound waves must not overlap on the walls.

The ceiling reflector should have a spherical formed surface, or one that has all points of the inside an equal distance from one generating point or focus. In most cases a reflector that has its surface struck from a radial distance that is equal to exactly twice the distance between the speaker, singer or musician and the ceiling, will return all language or vocal music directly vertical to the audience in an evenly graduated volume and timbre. An illustration of the paralleling principle of the concave spherical ceiling reflector is shown on page 83, the bottom illustration.

CHAPTER X.

DEAD OR NON-REFLECTING WALLS.

ALL WALLS and ceilings that, by their form and location, act as sound boards or reflecting walls, should be constructed as non-reflecting surfaces. If in a new building that is to be fire-proof in construction, use the following method :

Line the walls with hollow, porous terra-cotta, made from about equal parts of clay and sawdust, the sawdust being burnt out of the clay during the manufacture, thus leaving the terra-cotta of a light-weight, cork-like, sound-deadening substance. Overlay the porous lining with strips of V angle iron, laid horizontally and not over twelve inches between the centers, and cover the entire walls on top of V strip with heavy tinned wire-cloth, the meshes not to exceed three-eighths of an inch. Fill in the space between the wire-cloth and the hollow lining with closely packed mineral wool or asbestos fiber. Overlay entire wire-cloth with extra heavy unbleached factory cloth ; stretch the cloth very tight, and finish the walls with decorations to suit, either by frescoing, painting or papering.

Method No. 2.—Strip the walls with wood strips about one inch square, set not over twelve inches on centers. Overlay strips with wire cloth ; wire-cloth with heavy building-deadening felt or "Cabot's Seaweed Sheathing Quilt ;" the deadening felt with factory cloth, and finish as above.

Method No. 3, for Walls of Wood Construction.—Overlay with dry, matched lumber, half inch thick and not over 3½ inches wide. Strip the lumber sheathing with strips half an inch thick by one inch wide, laid not over twelve inches between centers. Overlay strips with heavy, waterproof building paper ; splice the paper on furring strips. Cover each furring with strip one-inch square, as counter-furring, and the counter-furring with wire-cloth and felt. Finish in the same way as No. 2.

OLD BUILDINGS.

The walls of old buildings may be made dead to sound reflections by the methods just described or in the following manner:

When the door and window finish is thick enough to allow of wall furring, then strip the walls with one-half inch by one-inch strips, not over twelve inches on centers. Cover with wire-cloth, and the wire-cloth with patent deadening cardboards. Overlay the cardboard with building felt, and the felt with factory cloth. Finish with paint or paper decorations.

Method No. 2.—Where impracticable to use furring strips, then place the felt under the cardboards and directly on the wall, instead of outside cardboards, as in above. Then cover the felt with the cardboard, and decorate directly on the cardboard, without either wire-cloth or factory cloth.

Method No. 3.—For an ordinary job in a cheap building, the cardboard may be used alone, laid directly on the wall. But this method will not give a perfectly dead wall—it will only be about 60 per cent. perfect.

Where an absolutely dead wall is desired, such a result can only be attained by finishing the surface of the wall with material that is of the nature of velvet. Such a surface is made by first painting the surface of the walls with a thick coat of cement of slow-drying varnish, and then forcing finely clipped wool into it by air blast while it is still fresh. The wool adheres to the cement and forms a heavy nap, from one-sixth to one-fourth of an inch thick, according to the length of the wool and the amount of cement applied to the walls.

In old buildings, where the rooms are finished with high wainscoting, paneled ceiling and massive door and window finish that have been painted and varnished year after year until the surface of wood-work is covered with a thick-glazed enamel coating that affords good sound reflection, the room may be considerably improved by first sand-papering the painted work until all the gloss is removed and then repainting with flat colors or paint without any gloss. Where walls are wainscoted, they may be finished in water color or fresco paint. In absence of wainscoting, same can be done with any wall above five feet from the floor.

TEMPORARY ACOUSTIC IMPROVEMENTS.

The number of old buildings with defective acoustic properties is so very great, their forms and sizes are of such unlimited variety and imperfections so varied that it is an impossibility to formulate any specific rules, formulas, methods or devices for their improvement. Different auditoriums require specific treatment in nearly every instance to meet particular conditions and requirements and produce satisfactory results. Hence, the following are offered more as suggestions than as specific rules to be followed with the expectation of remedying all evils in all cases. They are temporary remedies that the author has used many times with satisfactory results in demonstrating and testing defective auditoriums.

Large armories, drill halls or shooting galleries are improved about 20 per cent. by the spreading of common sawdust, to the thickness of one-half inch, evenly over the entire floor. If a band is playing at one end of the room, in close proximity to a brick or stone wall, then hang curtains between the band and the wall (about six inches from the wall surface will give the best results) and another improvement of about 10 per cent. can be added to the sawdust's 20.

In a long, narrow room that has an arched ceiling, hang curtains crosswise of the room from the ceiling down to the bottom of the arch or spring line. The distance between the curtains should not be greater than one half the width of the room. The greater the surface of the curtains the less will be the sound disturbance.

In auditoriums that have domes in the ceiling the best plan is to hang a curtain horizontally directly under or across the mouth or bottom of the dome. If the dome is used as a source from which light is supplied to the room, then the next best remedy for sound disturbances is cover the mouth of the dome with thin veiling, stretched tight across it.

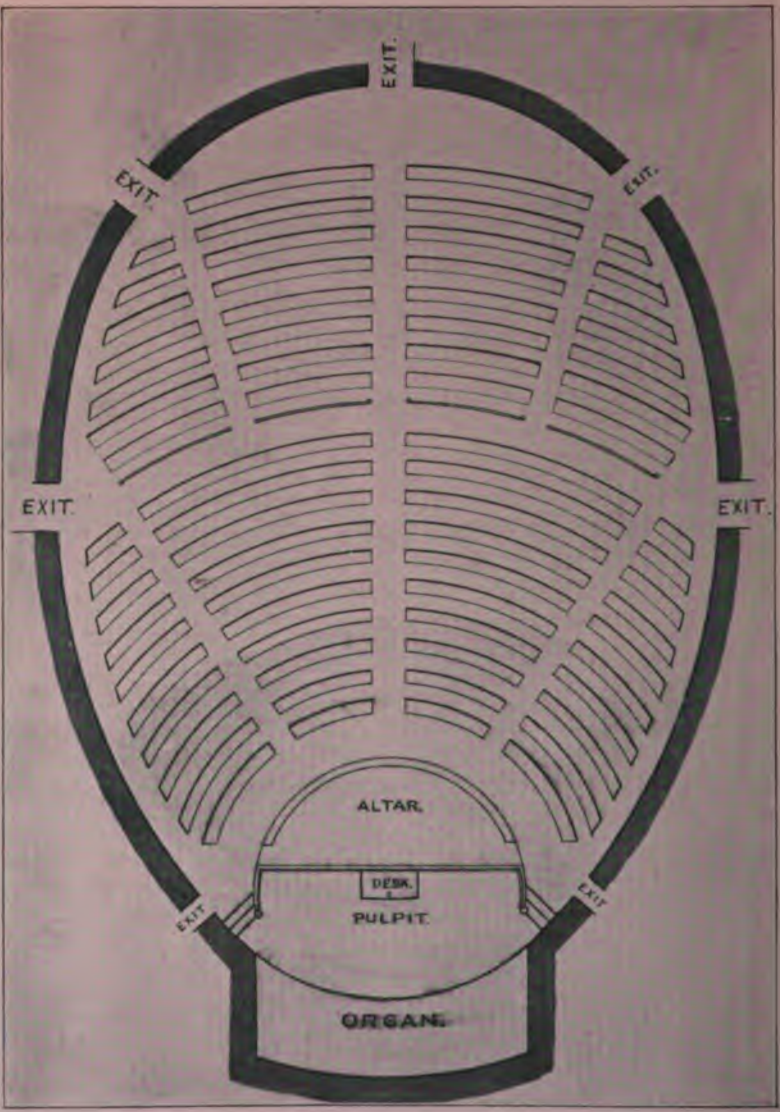
Where there is a cove in the building behind the pulpit or rostrum, stretch thin veiling over the mouth of the cove, about one foot back from the edge, over which hang heavy portier curtains.

Do not, if it can possibly be avoided, station a singer, orator or a musical instrument in front of or near any circular cavity.

The corner of a room is a much better location, but against a flat wall is the best.

A thick carpet or rug on the floor beneath an orator, singer or a piano will subdue the resonance. Tissue paper ornaments used as festoons from gas fixtures, along the gallery fronts, or over windows and doors, all assist in absorbing or killing echoes, reverberations, etc., and thus improving the hearing qualities of any auditorium.

All empty adjacent rooms that have connecting doors with the auditorium should have their doors closed during sound utterances by either singer or orator, as all rooms are primary resonance pockets and therefore, if connected with the auditorium through an open door, they will greatly augment any sound disturbances possessed by the auditorium.


EXIT.
EXIT.
EXIT.
EXIT.
EXIT.
ALTAR.
DESK.
PULPIT.
EXIT
EXIT
ORGAN.

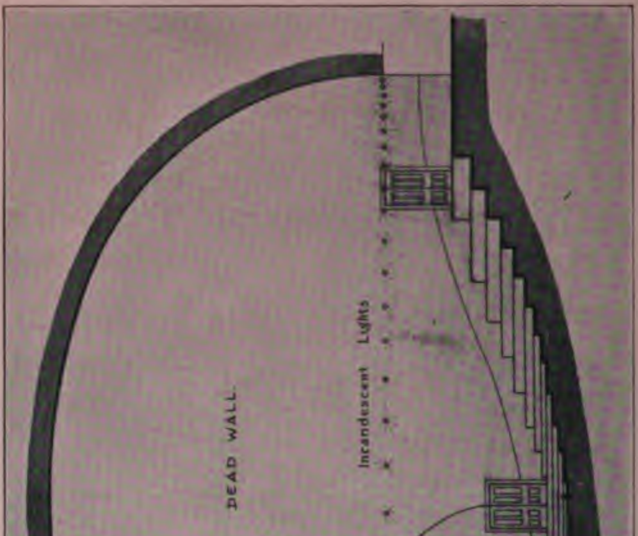
APPENDIX OF IDEAL AUDITORIUMS.

THE ILLUSTRATIONS on pages 96 and 98 are intended to represent a floor plan and a longitudinal section of a church auditorium that may be considered as ideally perfect in all of its constructive arrangements, without taking into consideration the artistic or decorative side of the principles involved.

The interior of the room is in a general way approximate to the form of an egg-oval. The windows, furniture, decorations, etc., are omitted from the illustrations for the sake of simplicity. The floor is constructed in a concave form, descending towards the pulpit in a series of steps or vertical offsets, having gradually diminishing heights from the outside wall towards the pulpit. The heights of the offsets are so graduated that the eyes of each and every auditor are about four inches above all persons in tier of seats directly in front of him, eight inches above all persons in second tier in front, twelve inches above third tier, and so on over entire seating space of the floor.

By this seating arrangement the orator or singer is afforded a clear and unobstructed view at all times of each and every person in the audience, while the listener has an equally good one of the pulpit or rostrum, and also a clear field view of each and every other person in the room, a view that cannot be obtained by any other method of seating.

The pulpit or stage lighting is furnished by an arc electric light, located above and in front of the speaker, in the same relative position that the sun would have to the earth at 9 o'clock


DEAD WALL
Incandescent Lights
REFLECTING WALL
Arc Light, Reflector
45°
ALTAR
PULPIT
ORGAN LOFT
Sound Board Wall

in the morning or 3 in the afternoon. The light should be enclosed in a tight reflector case that is of the proper form and size to throw the light over the entire pulpit, stage or rostrum, as the case may be, without overlapping on the floor space for the seats of the audience.

The auditorium lighting is furnished by a row of lights placed on the rear half of the outside walls, each light being enclosed in a pocket reflector in such a manner that it projects its light forward, covering a field of floor space not over 30 degrees in width. As all the lights show dark on the side view, a person may occupy a seat in any part of the room and enjoy an entertainment without being forced to look at or be blinded by a light—every light in the room being invisible to all persons in the audience at their front view, only showing at a backward glance.

The walls and ceilings are constructed of one continuous surface, all being built on a curve. All wall surface above and back of a parabolic curved line running from the top of the double doors, located about the center of the side walls, and terminating at the top of a vertical line which divides the organ loft from the pulpit, is made a dead or non-reflecting sound surface.

The wall space below the parabolic line is constructed as a sound reflector, of hard, smooth plaster finish. All walls of the organ loft are constructed on the true principles of a perfect sound board by the mirror system of demonstration, as described on pages 85 and 86.

For a more detailed description of plan for lighting, see pages 55-56.

The best system of heating is fully described and illustrated on pages 48 and 49.

A detailed description of sound boards and their construction can be found on pages 74-91.

These cuts represent the outline shapes of a floor plan and a longitudinal section of the famous Mormon Tabernacle at Salt Lake City, Utah.

This building is popularly considered the most acoustically perfect structure in the world. In the absence of authentic scientific demonstrations as to the facts of its acoustical perfection, the author refrains from any comments until an opportunity has been offered for making a proper diagnosis of the hearing properties it is supposed to possess, but he hopes to be able to give full details of his demonstrations in later editions of this volume.

The Tabernacle is nearly 150 feet wide by 250 long, and has a reported seating capacity of 11,000 persons.

The ancient Romans selected almost the exact outline form of floor plans as shown above when they erected that famous historical theater, "THE COLISEUM," at Rome centuries ago, thus demonstrating to the future population the practicability of the oval form of an auditorium for convenience and compactness in seating arrangements, and its desirability because it gives a clear and unobstructed view from every seat in its area and a flat field view of entire arena or stage. The dimensions of the building are 510 feet wide by 616 long, with arena 176 x 281 and a seating capacity for 87,000 people.

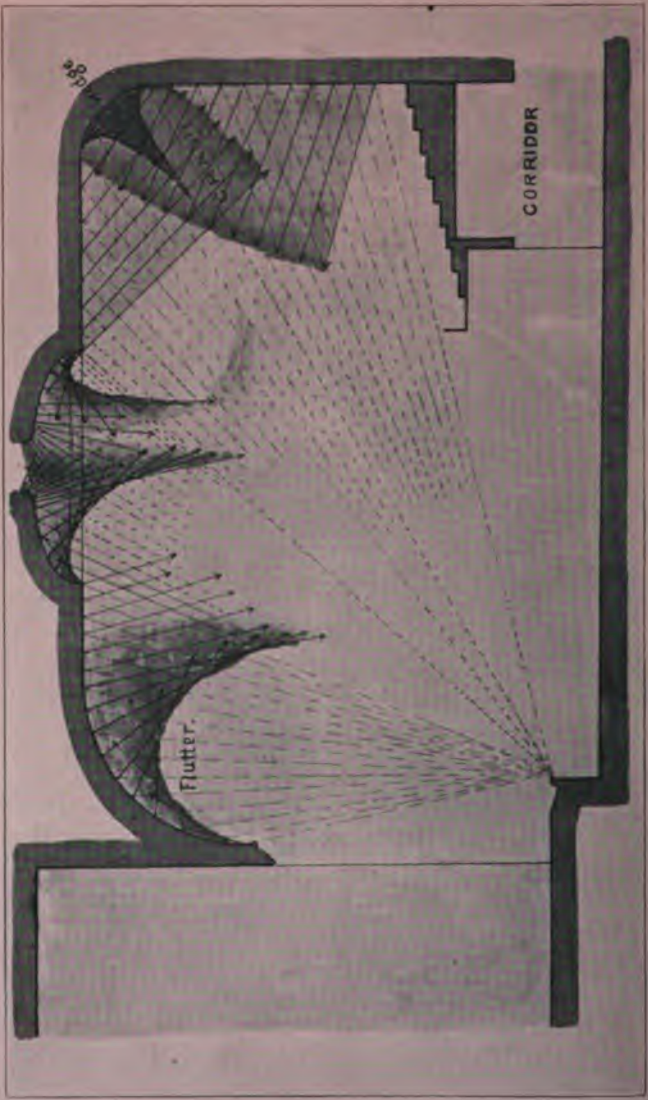
APPENDIX OF EXISTING FAILURES.

THE AUTHOR appends to this volume a few examples of buildings that are generally conceded by the public—and in each case to him personally known—to be deficient in acoustics. Some of them are total failures, and all are very bad to hear in.

The cuts show some of the greatest stumbling blocks to be avoided in the erection of auditoriums, and one or two in particular contain nearly all the known defects due to air disturbances in the whole category of acoustic troubles. They are offered simply to point out dangerous hidden rocks in shoal waters that should be avoided by every architect in the plans of an auditorium. I refrain from offering any information outside of the acoustical principles involved in the following examples for the reason that I am free from all desire to parade the faults or discrepancies of others before the critical eye of a not always too discriminating public.

The dotted lines show direction of travel of the sound waves, and the solid lines with arrow-heads show direction of reflected sound waves' travel.

The cut on following page represents a longitudinal section of a large theater that has a seating capacity of over 2,000. The dark portions show where the air disturbances occur. The proscenium Flutter and central dome Jar show the results of a prolonged sound. In the rear upper circular angle the Lapping Crash shows the position of the sound wave one-tenth of a second after issue from the stage. The Wedge, co-mingled with the Crash, extends full distance of the side and rear walls. This

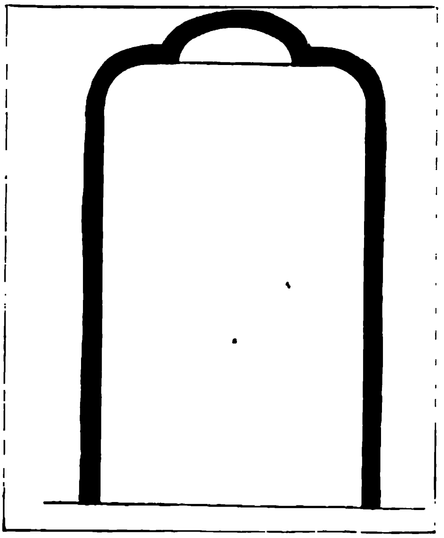


LONGITUDINAL SECTION OF A LARGE THEATER.

theater is a total failure acoustically. The building cost over a quarter of a million dollars. Repairs to the extent of nearly $100,000 are to be made to it this year (1898) to remedy acoustic defects.

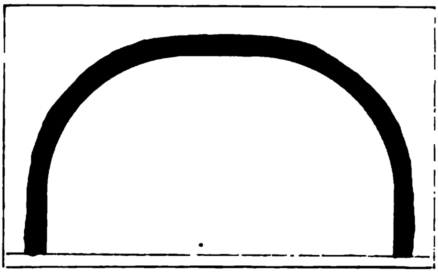
This building has a wide corridor at the rear of the auditorium that encircles the entire room except the space used for proscenium opening. The corridor extends behind the private boxes, located adjacent to the proscenium arch, and connects directly with the stage at each end, at the outer or wall side of the stage.

If the doors connecting the private boxes, or the doors between the end of the corridor and stage are left open during speaking or singing on the stage, the corridor is transformed into a very good speaking-tube, as nearly every word spoken or sung can be heard very distinctly in any part of the corridor, which acts as a resonance pocket or tube of the first order in the propagation of primary resonance.



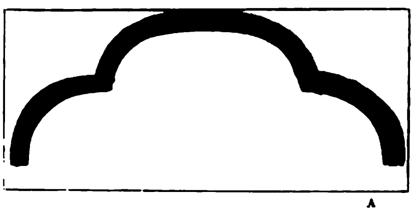
This cut represents the cross section, looking backward, of a large theater that seats about 2,400 people. The room is about 40 feet wide and about 90 feet high. The walls are plastered directly on the brick with patent hard plaster. It is a total failure acoustically. Cost about $220,000. It prolonged a note from a cornet until the author counted 16—about 4 seconds after the cornet ceased utterance.

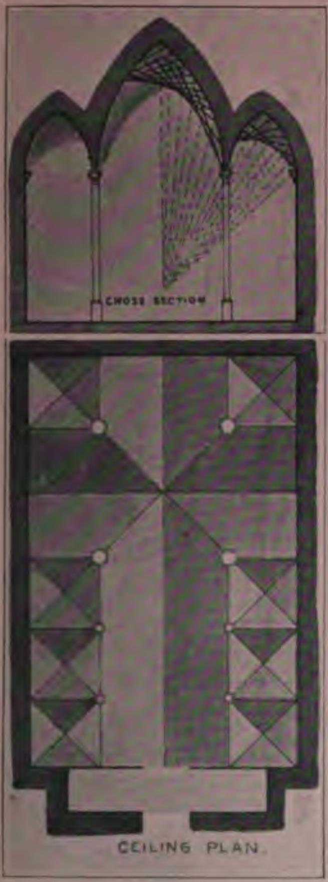
This cut represents a Town Hall, with dimensions of about 60 x 70 feet on the floor plan. The circular angles extend entirely around the room. The sound jumble is of such a nature as to baffle description. A band of 18 pieces rendered a selection of music in the center of the room. The music was so intermingled with echoes, crashes, etc., as to entirely destroy the melody—the author being unable to distinguish much difference between the music of "Home, Sweet Home" and "Marching Through Georgia."



This room also possesses the property of sound transmission during very loud sound disturbances, to wit: Two persons stationed at opposite diagonal corners, 90 feet apart, with their heads about six inches from the wall, can hear each other speak during the rendering of music by a brass band or the loud cheering of a political gathering. The words are transmitted clear and distinct, and even whispers can be heard.

This cut represents a cross section of a large church that has two side and one center wedge jars which extend the full length of the auditorium. A celebrated vocalist rendered a selection from the rostrum, located in the alcove, and the author occupied a seat about where the letter A appears under the cut. The selection rendered contained five verses of four lines with a simple melody. But two words in the entire selection were conveyed through the sound jumble to the ears of the author, the rest of the words being nullified. Of course this church is conceded to be an acoustic failure, and yet its erection is said to have cost over $100,000.





We here have cuts representing a cross section and plan, giving a ceiling view, of a large church—dimensions about 60 x 100 feet. The ceiling is of the groined arch style, having a series of resonance pockets at the side, with a cruciform center nave and transepts. The center has a double lapping flutter the entire length and width of the cruciform center. Thousands of dollars have been spent in stringing wire and making other experiments, one of which was the building of a false floor, set on an incline of about an 8-foot rise at the rear end of the room and descending on a wedge incline to the pulpit. A sound board, built hood fashion over the pulpit, was another expedient tried, but it was a failure. It still remains a total acoustical failure, church services not having been held in it for a number of years. The sound jumble is sufficient to make a person, with eyes closed, unable to locate the organ and chorus choir. About $90,000 was the amount of its cost when first erected.

The author quite recently examined a church that cost nearly $200,000, which possesses a peculiar simple resonance. The church is laid out on the cruciform plan or outline, with the transverse section very similar to the one shown above. The auditorium is of the right size and form to constitute in and of itself a perfect primary resonance pocket that is almost on the exact pitch of F natural in the major scale.

The church is provided with one of the latest improved pipe organs. The diapason rank of pipes, after being placed in correct voice and perfect tune, has the rank of flute pipes placed in perfect pitch with them, and then the clarionet rank is brought into harmony with the diapason.

Now, if the clarionet and flute stops are played simultaneously, or in unison, they will be discord to an unbearable degree. Then, again, in delicate phrasing, every time the note F is struck on the organ the room, with its resonance properties, will answer to its pitch and thereby increase the volume of the tone F about 50 per cent., greatly to the musical injury of the melody and to the embarassment of the organist.

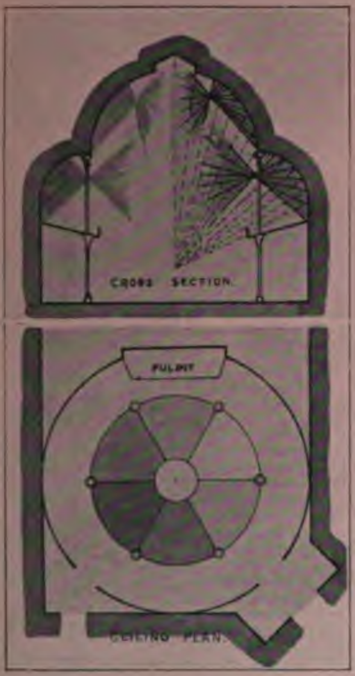
This auditorium, in its resonance results, is governed by the laws of sound augmentation by conjunction, as illustrated by tuning fork and resonance box on page 19.

Another church, that has been recently erected, has come under the observation of the author. The auditorium, by its compound resonance, is exactly the reverse in its results to the one we have referred to above, in that it kills or nullifies the tones on certain pitches to such a degree that quite frequently the nullified or subdued tones are scarcely audible ten feet away from the organ.

The cause for this nullification of tones is that some wall surface returns a sound wave to the organ pipe and re-enforces the sound wave at the nodal or points of rarefactions of the outgoing primary sound wave.

The law that controls this principle (nodal silence by interference) is illustrated on page 18.

The remedy in all such cases as those cited above is to remove all sound resonance by constructing or making all sound reflecting walls of dead or non-reflecting surfaces, as specified on page 92.



These cuts represent a church that is square on the outside, but has it walls so filled as to leave the floor plan of the auditorium nearly circular, with section as shown. This room is possessed of a crossing jar or wedge in continuity around the entire room, the same as shown in cut of the cross section.

The hearing is quite clear along the gallery on the line of the roof supporting columns, the location being directly underneath the nodal sound roofs formed by the crossing sound wedges; but in all other parts of this auditorium—and really the most important ones—its acoustic properties are sadly defective.

This building is also provided with a system of ventilation that is described on page 42, shown in illustration as a "*Ventilating Duct. A Total Failure.*" This system of ventilation is constructed by placing a register at the end of each pew and connecting it to a tin flue that is carried down through the floor to the basement and thence to the outside air. When the auditorium is heated the foul air rushes up into the room instead of ventilating it, as intended. The influx of foul air was found to be strong enough to extinguish a match two feet from the vent register. The system was such a nuisance that it was removed from the building.

INDEX.

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MEMORANDA.

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